

Revised
12/23/74
Jab

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT INITIATION

Date: February 8, 1974

Project Title: "Program to Analyze Six Band Multispectral Images and Fabricate a Fourier Transform Detector"

Project No.: A-1592

Project Director: Mr. R. G. Shackelford

Sponsor: NASA--George C. Marshall Space Flight Center; MSFC, Alabama

Effective December 21, 1973 Estimated to run until September 20, 1974 (Contr. Exp.)

Agreement: Contract NAS8-30534 Amount: \$ 29,960.00

Reports Required: Monthly Progress Reports; Final Technical Report.

Sponsor Contact Person (s):	
<u>Technical Matters</u>	<u>Contractual Matters</u> (thru GTRI)
Mr. J. H. Kerr--Principal	Mr. R. J. Whitcomb (ACO)
Mr. H. F. Smith--Alternate	ONRRR
George C. Marshall Space	Campus
Flight Center	
ATTN: S&E-ASTR-IA	
Marshall Space Flight Center,	
Alabama 35812	

INSE PRIORITY RATING: DO-A2 under DMS Reg. 1.

Assigned to SPECIAL TECHNIQUES Division

COPIES TO:

<input type="checkbox"/> Project Director	<input type="checkbox"/> Photographic Laboratory
<input type="checkbox"/> Director	<input checked="" type="checkbox"/> Security, Property, Reports Coordinator
<input type="checkbox"/> Assistant Director	<input type="checkbox"/> EES Accounting
<input type="checkbox"/> GTRI	<input type="checkbox"/> EES Supply Services
<input type="checkbox"/> Division Chief (s)	<input type="checkbox"/> Library
<input type="checkbox"/> Branch Heads	<input type="checkbox"/> Office of Computing Services
<input type="checkbox"/> Service Groups	<input type="checkbox"/> Project File
<input type="checkbox"/> Patent Coordinator	<input type="checkbox"/> Other

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION

Pool
ad
OHL

PROJECT TERMINATION

July 25, 1975

Date: _____

Project Title: Program to Analyze Six Band Multispectral Images and Fabricate a Fourier Transform Detector

Project No.: A-1592

Project Director: R. G. Shackelford

Sponsor: NASA - Marshall Space Flight Center

Effective Termination Date: June 21, 1975 (Contract Expiration)

Clearance of Accounting Charges: by June 30, 1975

Grant/Contract Closeout Actions Remaining: Final Invoice & Closing Documents
Final Report of Inventions
Gov't. Property Inventory & Certificate

Property

Special Techniques Department

Assigned to: _____

COPIES TO:

Project Director
Director, EES
Director, ORA/GTRI
Assistant Director
Division Chief
EES Accounting
Patent Coordinator

EES Supply Services
Photographic Laboratory
Security-Reports-Property Office
General Office Services
Library, Technical Reports Section
Office of Computing Services
Project File
Other Sue Corbin

A-1592

MONTHLY PROGRESS REPORT NO. 1

For the Period 21 December 1973 through 31 January 1974

PROGRAM TO ANALYZE SIX BAND MULTISPECTRAL IMAGES

By

R. G. Shackelford

Contract No. NAS830534

2 February 1974

Performed for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia 30332

Technical Discussion of Work Performed During the Reporting Period

Technical efforts during the first reporting period were directed toward setting up the Fourier Transform optical test bed, and in determining the electronic components required for extracting electrical signatures from the annular ring fiber optics detector.

The Fourier transform test bed consists of a Coherent Radiation Model 52B-A argon laser, a Tropel Model 750 Fourier Transform lens, a Recognition System's Model DPSU-2 diffraction pattern sampling unit, a spatial filter-beam expander assembly and associated optical components all mounted on a vibration isolated optical table. This system has been set up and tested by employing a series of fine mesh wire gratings to provide Fourier transform signatures which can be examined visually and recorded by locating the diffraction pattern sampling unit in the Fourier transform plane. The effects of laser beam size, spatial uniformity and alignment with respect to the Fourier transform lens on the quality of the Fourier transform signatures of the wire mesh images have been examined, and the basic configuration of the test bed has been determined.

The six band multispectral film was received from MSFC during this period, and specifications of the film and filters employed during its exposure have been obtained. Methods for mounting the film and for accurately locating the position of the laser beam on the film are being considered.

An analysis of the electronic components required for the fiber optics detector has been initiated. Selection of photodiodes and pre-amplifiers for this detector will depend on the dynamic range of the transform signatures resulting from the forestry images. This range has been estimated from experience with other photographic images to be about four decades. The upper and lower intensity limits can be adjusted over a wide range by utilizing the amplitude control on the laser power supply in conjunction with neutral density filters placed in the path of the laser beam. Direct experiments with the forestry photos will be required, however, for confirmation of the estimated intensity range.

Financial Statement

The expenditures to date are:

Technical Effort	\$2,344
Materials and Supplies	0
Travel	<u>0</u>
Total Expenditures to Date	\$2,344

The projected expenditures required for completion of the program are:

Technical Effort	\$25,416
Materials and Supplies	2,000
Travel	<u>200</u>
Total Projected Expenditures	\$27,616

Plans for the Next Reporting Period

It is anticipated that the GFE Fiber Optics Detector will be received during the next reporting period. As soon as this detector is received, a mount for incorporating it into the Fourier plane of the optical test bed will be designed.

Experiments for determining the resolution and dynamic range of forestry images will also be initiated during the next reporting period. Studies to determine the optical parameters and detector electronics required for the realization of a system to analyze the transform signatures of the six band images will continue.

MONTHLY PROGRESS REPORT NO. 2

For the Period 1 February 1974 through 28 February 1974

PROGRAM TO ANALYZE SIX BAND MULTISPECTRAL IMAGES

By

R. G. Shackelford

Contract No. NAS830534

7 March 1974

Performed for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia 30332

Technical Discussion of Work Performed During the Reporting Period

Technical efforts during the second reporting period included initiation of electronic circuitry design for the photodetector-electronic processor interface, and further refinements in characterization of the optical Fourier transform test bed. The GFE fiber optic detector was also received although the photodiodes and associated electronic components are not yet available.

During this reporting period the design of the electronic circuitry for the Fourier transform detector was reviewed. This circuitry provides the interface between the photodiodes, which detect the light collected by each ring of the fiber optic bundle, and the analog-to-digital converter which outputs the optical transform signature in digital form. The output of each photodiode is amplified to provide an input to an analog commutator. The commutator sequentially connects the output of the photodiode amplifiers to the input of a sample and hold circuit which provides the input to the analog-to-digital converter. Interface problems between the photodiodes and the amplifiers as well as those between the commutator and analog-to-digital conversion system have been investigated. Problems associated with interfacing the Fourier transform detector electronic system with digital processing equipment are also being considered at this stage of the design. The characteristics of selected digital processing systems, interface signals required and methods of data transfer were studied during this reporting period and a preliminary design of part of the interface system has been completed.

A study of schemes for mounting the 70 mm film in the optical processor led to some concern over the potential problem of the mounting hardware introducing noise into the optical processor. An experiment for measuring the optical noise spectrum in the Fourier plane caused by placing a liquid gate in the object plane was begun. Initial efforts to measure the noise spectrum with the Diffraction Pattern Sampling Unit have not, however, proven satisfactory, and the experiment will be repeated using photographic film as the detecting medium.

Financial Statement

The expenditures to date are:

Technical Effort	\$6,116
Materials and Supplies	0
Travel	<u>0</u>
Total Expenditures to Date	\$6,116

The projected expenditures required for completion of the program are:

Technical Effort	\$21,644
Materials and Supplies	2,000
Travel	<u>200</u>
Total Projected Expenditures	\$23,844

Plans for the Next Reporting Period

The noise characteristics of several candidate schemes for mounting the 70 mm film will be evaluated during the next reporting period, and a mounting design will be chosen. Initial measurements on the Fourier transform signatures of forestry images will begin as soon as a suitable film mount is fabricated.

During the next reporting period, portions of the electronic circuitry will also be breadboarded to verify design parameters and to evaluate some suspected problems. Interface requirements between the detector and processing equipment will continue to be studied, and the electronic components required for implementing the interface electronics will be ordered.

MONTHLY PROGRESS REPORT NO. 3

For the Period 1 March 1974 through 31 March 1974

PROGRAM TO ANALYZE SIX BAND MULTISPECTRAL IMAGES

By

R. G. Shackelford

Contract No. NAS830534

5 April 1974

Performed for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia 30332

Technical Discussion of Work Performed During the Reporting Period

Delays in delivery of materials and components relating to the 70 mm film mount and the electronic interface circuitry resulted in diversion of the work previously planned for this reporting period. Alternate tasks performed included cleaning and repair of the Image Forming Light Modulator (IFLM) which was developed at Georgia Tech under Contract NAS8-27375 (GFE), and continued study of the optical Fourier processor system.

The IFLM, which was supplied under Modification No. 1 to the subject contract was inspected and found to have a residue of unknown origin on all its interior surfaces. It was disassembled and cleaned with chemicals and an ultrasonic cleaner. All high vacuum gaskets were replaced and minor mechanical modifications were made to provide for acceptance of an improved electron gun, which was developed at Georgia Tech under Contract NAS8-29860. A new high voltage power supply was ordered to replace the existing IFLM supply which did not have the current capacity required to extract the maximum electron beam current from the improved electron gun.

Methods for aligning the Fourier transform processor were experimentally investigated, and a reliable technique was developed.

The diffraction pattern sampling unit was calibrated in terms of the output voltage corresponding to a known intensity at the detector surface. The spatially filtered and expanded laser beam was passed through a ground glass plate to reduce speckle and used to illuminate the surface of the detector containing the ring and wedge array. In this manner the smallest elements in the array were uniformly illuminated. The calibration was performed over a three decade range and the linearity was found to be good. It has been observed, however, that the zero order spot of a Fourier transform spatial distribution causes a halo to appear on the surface of the detector because of internal reflections at the window-detector interface. This halo represents an extraneous light distribution which distorts the information contained in the Fourier transform. Because of the dynamic range required for analysis of photographic images, this detector is not thought to be suitable for the intended application, and no further tests on this unit will be performed. Since the ring and wedge array represents

a potentially important configuration for analysis of the Fourier transforms of forestry images, a new detector array without a window has been ordered. This unit should not suffer from the halo effect and will provide the same desirable operating characteristics as the old unit.

During this period the interface problems associated with the optical Fourier processor and the various digital processors involved have also been studied in greater depth. Problems concerned with converting the optical transform signature data into a form suitable for input to the digital processor have been considered, and techniques for handling the data have been studied. Details of the interface control and data formats were investigated, and methods of coupling the digital processor and the optical processor over the necessary data and control lines to minimize ground loops were investigated. Balanced drivers and optical isolators appear to provide a solution to these coupling problems. Breadboarding of some key circuits has been delayed because of delays in delivery of their component parts. This work should be accomplished early in the next reporting period.

Financial Statement

The expenditures to date are:

Technical Effort	\$11,063
Materials and Supplies	1,108
Travel	<u>0</u>
Total Expenditures to Date	\$12,171

The projected expenditures required for completion of the program are:

Technical Effort	\$36,618
Materials and Supplies	10,892
Travel	<u>200</u>
Total Projected Expenditures	\$47,710

Plans for the Next Reporting Period

During the next reporting period, emphasis will be placed on operating the IFLM with the improved electron gun, mounting of the forestry images and the fiber optic detector in the Fourier transform processor, and finalizing the electronic system design.

A visit is also planned during the next reporting period to the Marshall Space Flight Center to discuss the technical details of interfacing the optical Fourier processor with the digital processor located there.

MONTHLY PROGRESS REPORT NO. 4

For the Period 1 April 1974 through 30 April 1974

PROGRAM TO ANALYZE SIX BAND MULTISPECTRAL IMAGES

By

R. G. Shackelford

Contract No. NAS830534

10 May 1974

Performed for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia 30332

Technical Discussion of Work Performed During the Reporting Period

Progress during the subject reporting period included operation of the IFLM with the high resolution electron gun, termination of the fiber optic detector bundles, mounting of the fiber optic detector housing, and finalization of the electronic design of the photodiode-computer interface.

Several new problems were encountered in the process of placing the IFLM and electron gun in operating condition. Included among the minor problems were a virtual vacuum leak in the high resolution electron gun, a malfunction in the emission control on the Orblon pump power supply, and a high voltage breakdown in the electron gun controller. These problems were resolved and the pressure in the IFLM reached 2×10^{-7} mm Hg after two days of pumping. The electron gun was aligned and a high intensity beam was obtained at an acceleration potential of 15 kV. One serious problem was discovered when the magnetic deflection circuits were activated. It was observed that the horizontal sweep was resulting in a distorted image with fold over at the beginning of the sweep. Experiments with the spare deflection coil revealed that eddy currents in the stainless steel tube supporting the electron gun housing were strongly affecting the horizontal deflection field. This effect is proportional to the square of the frequency of the field, and also proportional to the square of the wall thickness of the metal tubing. It was found experimentally that the field was not strongly affected for deflection frequencies less than 10 kHz and for a tubing wall thickness less than about 10 mils.

Since a 10 mil stainless steel tubing will not support the electron gun housing, a modification to the supporting structure will be required. This modification will involve mounting a ceramic tube inside the deflection coils to serve as a vacuum seal for the electron gun, and placing this assembly inside a stainless steel tubing which will be welded to the vacuum flange and the electron gun housing for support. The ceramic tubing will not give rise to eddy current effects because of its high resistivity. This modification is expected to take about two weeks.

The fiber bundles corresponding to each ring of the fiber optic detector have been terminated in a rectangular array in the top plate of

the detector housing. Measurements have been made to determine the coupling between adjacent rings of the detector, and the relative light output of each ring resulting from uniform illumination of the face of the detector.

Coupling between adjacent rings was found to be about 20 dB down, and the coupling to all other rings was found to be greater than 30 dB down. This performance is compatible with the exposure characteristics of photographic film and will not degrade the maximum contrast achievable with a particular film.

The relative light outputs of the 168 rings were found to closely follow the curve calculated from the ideal distribution of 3 mil fibers in concentric rings. The small variations recorded were attributed to variations in intensity of the light source illuminating the face of the detector and missing fibers in the rings resulting from non-uniform packing of the fiber bundle. These measurements will provide the basis for weighting of the electrical outputs from the photodiode which intercept the light outputs of the fiber optic rings.

A visit was made to MSFC on 16-17 April 1974 during which the electronic portion of the optical Fourier processor was discussed. A decision was made to purchase a Hewlett Packard 2313B analog-to-digital interface subsystem to provide the major portion of the required electronic system. This subsystem is compatible with the Hewlett Packard 2116B computer at MSFC and provides a general purpose capability of interfacing with other future systems as well as the optical Fourier processor. A decision was made that NASA would purchase the mainframe equipment of the 2313B subsystem and that Georgia Tech would purchase the six high level commutator boards required to provide the 168 analog inputs from the fiber optic bundles in the optical processor. The commutator boards have been placed on order with a quoted delivery of three weeks after receipt of order.

During this period consideration has also been given to the interface of the fiber optic bundles of the Fourier transform processor with the 2313B subsystem. This interface requires mounting of the photodiodes and providing the gain required between the photodiodes and the 2313B high level commutator inputs. Mounting techniques and arrangement of the operational amplifiers are being studied.

Interfacing the 2313B subsystem with a Data General Supernova computer to provide the acquisition of data for analysis at Georgia Tech is also being investigated. Discussions are being held with local Hewlett Packard representatives with respect to the interface requirements of the 2313B subsystem.

Financial Statement

The expenditures to date are:

Technical Effort	\$16,547
Materials and Supplies	6,800
Travel	<u>82</u>
Total Expenditures to Date	\$23,429

The projected expenditures required to completion of the program are:

Technical Effort	\$31,134
Materials and Supplies	5,200
Travel	<u>118</u>
Total Projected Expenditures	\$36,452

Plans for the Next Reporting Period

Modification of the electron gun mount will receive primary emphasis during the next reporting period. The mount for the 70 mm aerial film will also be machined and tested. Mounting of the photodiodes in an array corresponding to that of the fiber bundle termination plate has begun and will be continued during the next month. Initial measurements of Fourier transform signatures will begin when these tasks are completed.

During the next period, fiber optic multiplexer interface requirements and interface problems with digital processing equipment will continue to be considered. Discussions will continue with local Hewlett-Packard representatives to further clarify the digital interface requirements

MONTHLY PROGRESS REPORT NO. 5

For the Period 1 May 1974 through 31 May 1974

PROGRAM TO ANALYZE SIX BAND MULTISPECTRAL IMAGES

By

R. G. Shackelford

Contract No. NAS830534

13 June 1974

Performed for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia 30332

Technical Discussion of Work Performed During the Reporting Period

Initial operation of the Fourier transform optical processor was achieved during the reporting period. The 70 mm aerial film was introduced into the optical processor by means of a mechanical film transport which was fabricated during the reporting period, and Fourier transform signatures were recorded with a Recognition System's Diffraction Pattern Sampling Unit (DPSU).

Modifications to the IFLM electron gun mount were completed, and tests showed that the sweep distortion problem has been corrected.

Work on the optical digital interface unit was delayed pending arrival of electronic components required for mounting on the fiber optic detector housing.

Several techniques for introducing the 70 mm film into the optical processor were evaluated, and a mechanical transport was designed and fabricated. Liquid immersion was not employed because of reflection and scattering problems introduced by the optical windows. Noise attributed to the liquid gate was more objectionable than the spatial-phase-modulation noise introduced by film thickness variations.

Fourier transform signatures were recorded on the DPSU, but it was found that significant changes in the laser beam intensity were occurring during the recording interval. These observed changes, which were of the order of plus or minus ten percent, over the five minute recording interval would make it difficult to differentiate between transforms of similar images. It is likely that the transforms of different types of trees when viewed through a relatively low resolution image will be very similar, therefore good amplitude stability will be required from the laser.

It was found that the amplitude stability on the input side of the spatial filter was very good and the rms deviation could not be measured on the radiometer. The laser specifications state that the short term stability in the light control mode should be less than 0.2 percent rms and less than 0.2 percent drift per hour. The laser beam stability appeared to be in this range on the input side of the spatial filter. Several possible causes for the instability on the output side of the

spatial filter are being investigated. Vibration of the spatial filter relative to the laser would result in amplitude fluctuations, and the optical processor geometry has been changed to reduce the length of the optical path between the laser and spatial filter. Mode hopping or change in beam direction resulting from current fluctuations in the laser tube could also result in collimated beam instability. The laser mode pattern was investigated, and it was found that the laser was oscillating in higher order transverse modes on the 0.4880 μm transition at excitation currents over 10 amps. An internal aperture has been adjusted in the laser to eliminate the higher order transverse modes. The changes made to date have reduced the amplitude fluctuations from about 10 percent to about 2 percent. Further reduction may be achieved by stabilizing the laser on an electrical signal derived from the collimated laser beam intensity. This possibility will be pursued during the next reporting period.

Distortion in the horizontal scan of the IFLM was corrected by modifying the electron gun mount. This distortion was caused by eddy currents in the stainless steel tube on which the deflection yoke was mounted. The modification consisted of replacing the stainless steel tube with a ceramic tube, and enclosing the deflection yoke assembly in a stainless cylinder for support. Test indicated that the field inside the ceramic tube was essentially the same as the field produced by the deflection yoke without the ceramic tube present. The IFLM has been reassembled and the deflection system is much improved. The flyback time of the horizontal deflection system is too long at present causing some distortion on the left edge of the scanned raster. It is believed that this problem is one associated with the electronic driver for the horizontal deflection system and is not believed to be serious.

Hardware and software interface problems associated with the Hewlett Packard 2313B analog-to-digital interface subsystem and the Supernova computer continue to be studied. The high level commutator boards for the Hewlett Packard system have not been received as yet. Additional parts needed to construct circuitry to interface the photodiodes with the 2313B subsystem have been ordered.

Financial Statement

The expenditures to date are:

Technical Effort	\$23,207
Materials and Supplies	7,272
Travel	<u>82</u>
Total Expenditures to Date	\$30,561

The projected expenditures required for completion of the program are:

Technical Effort	\$24,474
Materials and Supplies	4,728
Travel	<u>118</u>
Total Projected Expenditures	\$29,320

Plans for the Next Reporting Period

Efforts during the next reporting period will be concentrated on improving the collimated laser beam amplitude stability and on placing the IFLM deflection system in proper operating condition. Work on the optical-digital interface will proceed on a schedule controlled by the delivery of essential components.

MONTHLY PROGRESS REPORT NO. 6

For the Period 1 June 1974 through 30 June 1974

PROGRAM TO ANALYZE SIX BAND MULTISPECTRAL IMAGES

By

R. G. Shackelford

Contract No. NAS830534

9 July 1974

Performed for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia 30332

Technical Discussion of Work Performed During the Reporting Period

Operation of the optical processor revealed several new problems whose solutions were pursued during the reporting period. These problems were associated with achieving a variable diameter laser beam with good spatial characteristics and good temporal stability.

Tests performed with the IFLM revealed several more minor problems which were corrected. The modulation capability of the electron gun will be investigated in more detail during the next reporting period.

Some components for the electronic interface systems have been received, and a study of possible interface techniques has continued.

Fourier transform signatures of areas on the aerial photographs illuminated by a variable diameter laser beam were measured. These measurements revealed that the technique employed for achieving the variable beam diameter was unsatisfactory. This technique consisted of expanding the laser beam with a spatial filter and beam collimator and placing an iris diaphragm between the collimator and film plane. The intensity was kept constant by a feedback light control system which sampled the beam which was projected through the iris. It was found that the leaves of the adjustable diaphragm result in a Fourier transform which obscures the desired signatures of the information content of the aerial photograph. The proposed solution to this problem is to modify a spatial filter mount to accept collimating lenses of varying focal lengths.

The laser amplitude stabilization scheme discussed in the previous progress report has been implemented and has been experimentally found to keep the amplitude stable within $\pm 0.5\%$ during the recording time of five minutes which is required with the DPSU.

Problems associated with the IFLM electron beam deflection system have been mostly resolved during this period. A problem involving a significant displacement of the scanned raster which required an offset current in the deflection system was found to be associated with the stray magnetic field from a Varian pump magnet which was being used temporarily with the IFLM. Removal of the magnet resulted in normal operation of the deflection centering controls. The increased flyback time in the horizontal deflection system

was found to be a result of increased drive requirements associated with the geometry of the present deflection coil system and the accelerating voltages used. For the horizontal deflection driver design which presently exists, this geometry results in a smaller scanned area when the proper flyback time is realized. Some problems still exist with the electrostatic deflection modulation of the electron gun beam current. The extent of these problems has not as yet been determined. Some consideration has been given to the possibility of using the beam modulation system as originally designed if these problems are found to be significant.

Interface considerations involving the Hewlett Packard 2313B analog-to-digital interface subsystem continue to be investigated. A decision on the method of interface between the 2313B and the digital data processors involved has not as yet been made. The Hewlett Packard 12751A high level multiplexer circuit boards which make up part of the 2313B system were received during this period; however, some parts required for the interface between the photodiodes and the 2313B system have not as yet been received.

Financial Statement

The expenditures to date are:

Technical Effort	\$27,440
Materials and Supplies	7,272
Travel	<u>82</u>
Total Expenditures to Date	\$34,794

The projected expenditures required for completion of the program are:

Technical Effort	\$20,241
Materials and Supplies	4,728
Travel	<u>118</u>
Total Projected Expenditures	\$25,087

Plans for the Next Reporting Period

Operation of the optical processor and analysis of Fourier transforms of the aerial photographs will continue during the next reporting period. The IFLM will be tested with a KD^*P crystal target and the modulation system will be evaluated. Construction of the photodiode-to-analog multiplexer interface will be initiated, and the multiplexer-to-data processor interface design will be finalized.

MONTHLY PROGRESS REPORT NO. 7

For the Period 1 July 1974 through 31 July 1974

PROGRAM TO ANALYZE SIX BAND MULTISPECTRAL IMAGES

by

R. G. Shackelford

Contract No. NAS830534

15 August 1974

Performed for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia 30332

Technical Discussion of Work Performed During the Reporting Period

A malfunction in the radiometer detector which is being employed in the laser amplitude stabilization scheme precluded the acquisition of data on the coherent optical processor during the past reporting period.

Technical efforts during this period were concentrated on operation of the IFLM and evaluation of parameters relating to its use in the optical processor.

It was found that dust particles floating through the laser beam contribute to the amplitude noise component observed in earlier tests, and the optical path and components have been enclosed with plastic covers in an effort to reduce this effect. Shortly after this modification was completed, the radiometer detector employed in the laser amplitude stabilization circuit quit working, and it was found necessary to order a replacement component. This component is expected to arrive soon, and the detector should be operational during the next reporting period.

Operation of the IFLM and evaluation of its performance resulted in several decisions for modifications. The image projected on the laser beam was not found to have adequate resolution or contrast for application to optical processing of aerial photographs. The problem in contrast results partly from the poor polarization characteristics of the laser beam, and partly from inadequate current or too large an electron beam spot at the KD^{*}P crystal. The laser beam polarization problem has been solved by placing an additional polarizer at the output of the beam expander to reduce the polarization distortion incurred in transmission through the spatial filter-beam expander assembly. For imaging applications, a high quality polarizing material is required to prevent amplitude variations from being imposed on the laser beam and reducing the image resolution. It was found that a beam current of 7 μ A could be obtained from the electron gun under operating conditions which would not appear to reduce the life of the filament or damage the small metal apertures in the electron beam lenses. The beam diameter however, has not as yet been accurately measured.

The deflection plate modulation scheme appears to reduce resolution to an unacceptable level. When viewed on a fluorescent screen, the image

appears to be considerably worse than one would expect from the appearance of the unmodulated raster. The problem may result from movement of the beam spot at the target when the amplitude of the beam is modulated by the deflection plate-aperture scheme. The original grid modulation scheme will be reassembled, and a direct comparison will be made.

Originally it was planned to analyze the data obtained from the optical Fourier processor by writing a magnetic tape using the Supernova computer and taking the tape to the Univac 1108 computer for analysis. This was necessitated by the fact that no Fortran compiler is available on the Supernova computer. Recently Georgia Tech has purchased a Hewlett Packard 2100S computer which will be available for use on the project around 1 September 1972. Since the 2313B data acquisition subsystem is designed to be used with the 2100 series computers and a Fortran compiler is available with this computer, it is no longer necessary to interface with the Supernova computer. This should greatly reduce the computer interface problems. Techniques for using the Hewlett Packard 2313B subsystem and computer are being studied. Delivery of some of the components which will be used in the interface circuitry between the photodiodes and the input to the 2313B subsystem has been delayed another month by the vendor. This delay is being investigated and the possibility of substitution of equivalent components from another vendor is being considered. Design of this interface circuitry will be reviewed and construction started during the next period.

Financial Statement

The expenditures to date are:

Technical Effort	\$31,206
Materials and Supplies	7,988
Travel	<u>184</u>
Total Expenditures to Date	\$39,378

The projected expenditures required for completion of the program are:

Technical Effort	\$16,475
Materials and Supplies	4,012
Travel	<u>16</u>
Total Projected Expenditures	\$20,503

Plans for the Next Reporting Period

The primary goal for the next reporting period will be the measurement and analysis of Fourier transform signatures of the forestry film. Work on the electronics for the fiber optic detector and the detector-computer interface will also continue.

A-1592

Monthly Progress Report No. 8
For the Period 1 August 1974 through 31 August 1974

PROGRAM TO ANALYZE SIX BAND MULTISPECTRAL IMAGES

by
R. G. Shackelford

Contract No. NAS830534

19 September 1974

Performed for
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia 30332

Technical Discussion of Work Performed During the Reporting Period

During the past reporting period, a scheme for eliminating optical noise caused by scattering in the window of the DPSU was investigated. Tests were also performed to determine the stable operating range and input light intensity required for the operational amplifiers which will be employed with the fiber optic detector array. The remaining electronic components for the detector and interface system have been received, and layout of the printed circuit boards has begun.

Since it appears that delivery of the new DPSU detector array which was ordered in February will be delayed indefinitely, a scheme was devised to reduce the scattering from the window of the existing DPSU detector which arises from the intense undiffracted part of the Fourier transform. This scheme consisted of mounting a 10 mil plastic optical fiber just ahead of the transform plane so that it terminates with its axis coincident with the optical axis of the processor. In this manner, most of the undiffracted spot of the Fourier transform is intercepted by the optical fiber and diverted from the transform plane. This technique appears to work well, but further comparisons using transforms from simple images will be required. An electronic scanning unit which will be used to sample the outputs of the photodetectors in the DPSU and display these signals on an oscilloscope is being assembled. This unit will allow rapid acquisition and graphical display of the Fourier transform signatures.

Tests were conducted to determine the stable operating range of the Fairchild 747 operational amplifiers which will amplify the PIN diode outputs to a level suitable for input to the computer interface electronics. The maximum gain for stable operation of the 747 op amp was found to be approximately 10^6 V/A, and the input light intensity necessary to satisfy this stability requirement and the resolution of the interface circuitry was found to be approximately 1×10^{-7} W. This intensity level is well within the capabilities of the Fourier transform processor employing the argon laser as the coherent light source. Measurements to determine the linearity of the PIN photodiode operational amplifier combination are also being performed, and will be completed during the next reporting period.

Layout of the printed circuit boards which will accommodate the operational amplifiers has begun, and these boards should also be completed during the next reporting period.

Financial Statement

The expenditures to date are:

Technical Effort	\$34,412
Materials and Supplies	8,363
Travel	<u>185</u>
Total Expenditures to Date	\$42,960

The projected expenditures required for completion of the program are:

Technical Effort	\$13,269
Materials and Supplies	3,637
Travel	<u>15</u>
Total Projected Expenditures	\$16,921

Plans for the Next Reporting Period

The primary goal for the next reporting period is to complete work on the fiber optic detector array, and to employ this array in measuring Fourier transform signatures. Other efforts will include completion of interface wiring and initial operation of the Hewlett Packard 2313B interface subsystem.

MONTHLY PROGRESS REPORT NO. 9

For the Period 1 September 1974 through 30 September 1974

PROGRAM TO ANALYZE SIX BAND MULTISPECTRAL IMAGES

By

R. G. Shackelford

Contract No. NAS830534

15 October 1974

Performed for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia 30332

During this reporting period progress has been made, although at a slower rate than was initially anticipated, on the analog-digital processing electronics. The operational amplifier system coupling the photodiodes to the input of the Hewlett Packard 2313B analog commutation and analog-to-digital conversion system has been completed. The layout of the circuit boards for the operational amplifiers has also been completed and the negatives prepared for production of the boards. The Hewlett-Packard 2100S computer has been received and the 2313B commutator system interfaced with it. A bad circuit board in the 2313B commutator has been replaced, and proper operation of the system has been achieved.

An investigation of the vacuum system integrity of the IFLM housing has continued at a lower rate of effort, and a leak at the welded junction of one of the mechanical feed-throughs in the electron gun housing has been discovered and repaired. The electron gun has been reassembled, and contrast and resolution tests will be performed if it can be done without jeopardizing the primary objectives of the program.

Financial Statement

The expenditures to date are:

Technical Effort	\$37,333
Materials and Supplies	9,011
Travel	<u>185</u>
Total Expenditures to Date	\$46,529

The projected expenditures required for completion of the program are:

Technical Effort	\$10,348
Materials and Supplies	2,989
Travel	<u>15</u>
Total Projected Expenditures	\$13,352

Plans for the Next Reporting Period

The performance goals for the next reporting period are completion of the photodiode-operational amplifier circuit board, and checkout of the electronic portion of the processor from the photodiodes through the HP 2100S computer.

It would appear that based on the present rate of effort, completion and initial checkout of the optical processor will be achieved; however, extensive analysis of techniques for interpreting forestry images will not be possible within the limitations of time and funds remaining on this program. The technical difficulties relating to much longer than expected delivery times on components, and diversions of effort required to solve technical problems not anticipated at the beginning of this program have been documented in the previous monthly progress reports.

It has not been possible to perform the preliminary analysis of the optical Fourier transform signatures generated from the six-band aerial film because the diffraction pattern sampling array on which these measurements were predicated has not been received. This component was ordered in February 1974 with a delivery of 60 days, and has been repeatedly delayed since that time with no firm delivery date promised by the manufacturer. It will, therefore, be necessary to perform the preliminary analysis phase of the measurements after the fiber optic detector array is mated to the electronic processing system.

With the concurrence of the Contracting Officer Representative, we propose to perform measurements in the time remaining which will, if possible, establish the basic feasibility of the technique for classification of trees from the aerial film that has been supplied GFE on this program. The optimization of processing techniques would be a proper topic for further research providing feasibility of the basic technique can be established.

MONTHLY PROGRESS REPORT NO. 10

For the Period 1 October 1974 through 31 October 1974

PROGRAM TO ANALYZE SIX BAND MULTISPECTRAL IMAGES

By

R. G. Shackelford

Contract No. NAS830534

19 November 1974

Performed for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia 30332

Technical Discussion of Work Performed During the Reporting Period

During this reporting period, construction of the operational amplifier circuit boards was completed. These circuit boards provide the operational amplifier interface between the photodiodes and the Hewlett Packard 2313B analog commutation system. Mounting of components on the circuit boards has begun, mounting of the photodiodes in the plate which interfaces with the fiber optic bundles has been completed, and the diodes have been wired to the input connectors to the operational amplifier circuit boards. Construction of the cables which connect the operational amplifier boards to the 2313B system is also underway. Programs have been written for the 2100S computer so that the photodiode outputs may be sequentially sampled and displayed on an oscilloscope.

Financial Statement

The expenditures to date are:

Technical Effort	\$41,045
Materials and Supplies	9,637
Travel	<u>185</u>
Total Expenditures to Date	\$50,867

The projected expenditures required for completion of the program are:

Technical Effort	\$ 6,636
Materials and Supplies	2,363
Travel	<u>15</u>
Total Projected Expenditures	\$ 9,014

Plans for the Next Reporting Period

During the next period the circuit boards and cables will be completed and checkout of the system will begin. Consideration will also be given to analysis programs for optical classification of forestry data.

MONTHLY PROGRESS REPORT NO. 11

For the Period 1 November 1974 through 30 November 1974

PROGRAM TO ANALYZE SIX BAND MULTISPECTRAL IMAGES

by

R. G. Shackelford

Contract No. NAS830534

11 December 1974

Performed for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia 30332

During this period construction of the operational amplifier current-to-voltage converters which provide the interface between the photodiodes and the Hewlett-Packard 2313B analog commutator have been completed. Cabling connections between the converters and the commutator have also been completed. Checkout of the system was started and operation of the electronic systems appears to be satisfactory.

Software to control the analog commutator through a Hewlett-Packard 2100 series digital computer was developed. Some software difficulties were encountered but these difficulties have been worked out and the control programs are presently operating satisfactorily. The control programs provide the capability of printing all or portions of a data set in either linear or logarithmic form. Also provided is the ability to sample one set of data and display it on an oscilloscope in a refresh mode or to make sequential data set samples and display these on an oscilloscope so that changes in the transform data can be observed on a continuous basis.

Financial Statement

The expenditures to date are:

Technical Effort	\$46,220
Materials and Supplies	9,698
Travel	<u>185</u>
Total Expenditures to Date	\$56,103

The projected expenditures required for completion of the program are:

Technical Effort	\$ 1,461
Materials and Supplies	2,302
Travel	<u>15</u>
Total Projected Expenditures	\$ 3,778

Plans for the Next Reporting Period

During the next period the fiber optics will be interfaced with the electronic system and transform data for the forested areas of interest will be studied. A no-cost time extension of 60 days has been requested to allow time for evaluation of the optical processor system performance. Although the remaining funds will not permit an extensive evaluation, tests will be performed to provide a basis for determining the feasibility of tree classification by optical processing of multispectral film.

LIBRARY DOES NOT HAVE :

Monthly Progress Report nos. 12, 13 and 14

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
Atlanta, Georgia 30332

FINAL REPORT

PROJECT NO. A-1592

A STUDY TO ANALYZE SIX BAND MULTISPECTRAL IMAGES
AND FABRICATE A FOURIER TRANSFORM DETECTOR

by

R. G. SHACKELFORD

and

J. R. WALSH, JR.

RESEARCH CONTRACT NAS8-30534

21 December 1973 to 21 June 1975

Performed for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

ABSTRACT

This report describes the design, development and fabrication of a hybrid optical-digital Fourier transform detector for automatic diffraction pattern analysis. The detector was designed around a concentric ring fiber optic array developed at Georgia Tech under NASA contract NAS8-28215. This array was formed from approximately 89,000 - 3 mil diameter optical fibers which were sorted into 168 concentric rings about a single fiber. All the fibers in each ring were collected into a bundle and terminated into a single photodetector. An optical/digital interface unit consisting of a high level multiplexer and an analog-to-digital amplifier for sampling the outputs of the photodetector - operational amplifier pairs terminating each ring of the fiber optic array was also constructed and is described in this report.

Analysis of the sampled diffraction pattern was accomplished by a digital data processing system, and the software developed for processing Fourier transforms of aerial photographic imagery is described. System parameters relating to the classification of forestry are discussed, and recommendations for improving system performance and utilizing spectral information available from conventional aerial photographs are also included.

TABLE OF CONTENTS

I. INTRODUCTION	1
II. SYSTEM CONSIDERATIONS	4
III. FIBER OPTIC DETECTOR	16
A. Fabrication Details	16
B. Performance	19
IV. OPTICAL/ELECTRONIC INTERFACE SUBSYSTEM	29
A. Subsystem Description	31
B. Computer Program	45
C. Subsystem Characteristics	53
V. SYSTEM PERFORMANCE	60
VI. CONCLUSIONS AND RECOMMENDATIONS	76
VII. ACKNOWLEDGEMENTS	79
VIII. REFERENCES	80

LIST OF TABLES

Table	Page
I. Aerial Photographic Data	5
II. Aerial Film Characteristics	6
III. Photographic Characteristics of Incoherent-to-Coherent Imaging Devices.	8
IV. Fiber Optic Array Layout - Ring Number vs. Row and Column on Mounting Plate	20
V. Photodiode Characteristics	22
VI. Circuit Board No. 1 Connections	39
VII. Circuit Board No. 2 Connections	40
VIII. Circuit Board No. 3 Connections	41
IX. Circuit Board No. 4 Connections	42
X. Circuit Board No. 5 Connections	43
XI. Circuit Board No. 6 Connections	44

LIST OF FIGURES

Figure	Page
1. Maximum Calculated Resolution of the 70 mm Aerial Film	9
2. Comparison of Two Aerial Photographs of an Urban Area (13,600 x 17,000 ft.)	11
3. Comparison of Two Aerial Photographs of Rural Areas (13,600 x 17,000 ft.)	12
4. Geometry of the Fourier Transform Optical Processor	14
5. Fiber Optic Detector Housing	17
6. Face of the Fiber Optic Array with Every Eleventh Ring Illuminated on the Mounting Plate	18
7. Photograph of the Fiber Optic and Photodiode Mounting Plates	21
8. Radial Distribution of Fiber Optic Detector Power Output for Uniform Illumination	24
9A. Fiber Optic Array Light Distribution Resulting from Illumination of Column 10 on the Fiber Bundle Mounting Plate	25
9B. Fiber Optic Array Light Distribution Resulting from Illumination of Column 11 on the Fiber Bundle Mounting Plate	26
9C. Fiber Optic Array Light Distribution Resulting from Illumination of Column 1 on the Fiber Bundle Mounting Plate	27
10. Arrangement of Photodiodes and Circuit Boards	30
11. Block Diagram of Optical Processor Electronic System	32
12. Schematic Diagram of a Dual Current-to-Voltage Converter . . .	33
13. Schematic of Reference Voltage Supply.	35
14. Photograph of a typical Circuit Board (Circuit Board No. 2). .	36

LIST OF FIGURES (Continued)

Figure	Page
15. Circuit Board Input and Output Connections	38
16. Main Fortran Program	47
17. Subroutine RDAD for Reading and Scaling Data from the HP 2313B Subsystem	48
18. Subroutine RD	49
19. Original RDAD Subroutine	50
20. Assembly Language Routine IS	52
21. Fortran Subroutine LGDTA	54
22. Subroutine WTDAL for Writing the Logarithm of the Observed Light Values on an Oscilloscope	55
23. Zero Light Intensity Voltages for Channels 1-33	58
24. Histograms of Voltage Readings on Selected Channels	59
25. Linearity of the Photodetector-Operational Amplifier Pair . .	62
26. Geometry of Fiber Bundle - Photodiode Termination and Radiation Loss Calculations	63
27. Radial Distribution Function of the Diffraction Pattern Sampling System	64
28. A Photograph of the Automatic Diffraction Pattern Sampling System	69
29. Diffraction Pattern and Automatic Diffraction Pattern Sampling System Display for a 250 Line/inch Grating Object	70
30. Aerial Photograph of a Section of Redstone Arsenal	72
31. Diffraction Pattern and Automatic Diffraction Pattern Sampling System Display of a Parallel Line Structure on an Aerial Photograph of a Section of Redstone Arsenal, Ala. .	73
32. Enlarged Aerial Photograph of Row Crops and the Resulting Fourier Transform Showing Strong First Order Maxima	74

I. INTRODUCTION

One of the most promising potential applications of coherent optical processing is real time land use classification from a satellite or conventional aircraft platform. Successful development of techniques and equipment for this application would provide land use planners with large scale, up-to-date information which is currently unavailable.

The critical elements in the development of a real time coherent optical land use processing system are the formation of coherent optical images of the terrain in real time, and the extraction of unique spatial signatures for the terrain features of interest. Successful solution of the imaging requirement is well underway with the on-going development of a variety of incoherent-to-coherent imaging devices utilizing liquid crystals, electro-optic single crystals, hot pressed ferroelectric ceramics, and thermoplastics. Techniques for real time exploitation of spatial signatures have not, however, been extensively developed, and the goal of this program has been the design, fabrication and testing of an automatic diffraction pattern analysis system.

Optical processors are capable of performing virtually instantaneous linear transformations on two dimensional data. The Fourier transforming property of a lens can be employed to obtain a spatial signature of any complex image in real time. Some means of sampling and processing this diffraction pattern is necessary if the optical processor is to be used to recognize a particular feature of the image. Matched filters have been employed to perform a cross correlation operation for identification of spatial features. This technique, while effective for many applications, is sensitive to image size and orientation, and registration of the Fourier transform pattern and the filter, and is best suited to the analysis of imagery for which these factors can be precisely controlled.

An alternative procedure for spatial feature analysis is sampling of the diffraction pattern by an array of photodetectors in conjunction with digital processing of the sampled outputs. Even though the digital

processing is a sequential operation, real time analysis is possible in many applications because of the data compression resulting from the optical Fourier transformation, and the relative simplicity of the pattern recognition operations compared with the Fourier transform operation. This combination of optical and digital processing for diffraction pattern analysis represents a hybrid configuration which efficiently utilizes the merits of both processing techniques.

The sampling geometry is an important consideration in a hybrid optical-digital diffraction pattern analyzer. The Fourier transform of a two dimensional object located at any position in the front focal plane of a Fourier transform lens is centered on the optic axis in the back focal plane of the lens. Thus the position of the Fourier transform of an object is independent of the position of that object in the front focal plane, and the sampling operation is always centered on the same space in the back focal plane of the transform lens. Although the Fourier transform is invariant to translation of the object, it is directly dependent on the angular orientation of the object. For this reason, the sampling geometry chosen for the hybrid optical-digital system described in this report consists of optical fibers arranged in concentric rings about a centrally located fiber. The bundle of fibers is oriented with the fiber's axes coincident with to the optical axis, and the ends of the fibers terminated in the diffraction pattern plane. All the fibers in each concentric ring are bundled together and terminated into a single photodetector. Including the central fiber there are approximately 89,000 optical fibers sorted into 168 rings which are terminated into 168 photodetectors. In this manner, each ring in the diffraction pattern plane corresponds to a specific spatial frequency with bandwidth equal to the diameter of the optical fiber.

The output of the photodetectors is a signal which is proportional to the intensity profile of the Fourier transform spatial frequency distribution. This spatial frequency signature is independent of orientation or location of the image feature in the image plane, and can be readily analyzed by a small digital computer. This report describes the development of an automatic hybrid optical-digital diffraction pattern analysis system for

forestry classification from aerial photographs. The design and development of the fiber optic detector array, the optical-digital interface system, and the software employed for analysis are described in the following sections of this report.

II. SYSTEM CONSIDERATIONS

One of the most important system considerations is the means by which data is introduced into the coherent optical processor. Real time operation will eventually require the use of an incoherent-to-coherent image converter; however, at this time a number of practical considerations discourage their use. Since the goal of this project was the investigation of techniques for automatic diffraction pattern analysis, the superior sensitivity and availability of aerial photographic transparencies provided a compelling basis for their choice as the input medium.

The 70 mm aerial transparencies whose characteristics are listed in Table 1 were provided by MSFC for analysis on this program. These transparencies were first generation copies of aerial photographs which were taken by six Hasselblad cameras. These cameras employed 40 mm wide-angle lenses and were pointed to a common focal spot corresponding to an altitude of 60,000 feet. Spectral coverage from the UV to the infrared was obtained by an appropriate combination of filter and film response characteristics.

The function of the input medium is to generate by laser beam projection a coherent image whose resolution is high enough to result in unique Fourier transform signatures for the objects in question. In this study, the objects were trees, and the desired optical processing operation was the discrimination of coniferous and deciduous classes. This study involved the investigation of techniques for analysis of the optically generated Fourier transform diffraction patterns of forestry images.

The resolution obtained in aerial photography is limited by the quality of the camera's optical system, and the film's inherent resolution, and is also strongly effected by atmospheric conditions, exposure parameters, and processing techniques. The nominal resolving power and exposure index for the different film types employed in the 70 mm aerial photographs are shown in Table 2. The resolving power was determined by procedures outlined in the American National Standards Institute (ANSI) bulletin PH2.33-1969. Where available, the Modulation Transfer Function (MTF) characteristics

Table I. Aerial Photographic Data

Date: May 21, 1971 - Mission 166/177 Tennessee Valley

SENSOR	Hass 1	Hass 2	Hass 3	Hass 4	Hass 5	Hass 6
FOCAL LENGTH	40 mm	40 mm	40 mm	40 mm	40 mm	40 mm
FILM TYPE	2402	2402	2424	SO-356	2443	2443
FILTER TYPE	25	58	89B	2E	W15	W15 + 10C
ROLL NUMBER	40	41	42	43	44	45
ALTITUDE		60,000 ft.				
FRAMES	061 → 072: From Tishomingo State Park, Miss. to Summerville, Ga. 073 → 084: From Sulphur Springs Station, Ga. to Luka, Miss.					

Table II. Aerial Film Characteristics^Δ

FILM	TYPE	EXPOSURE INDEX (ASA expect as noted)	RESOLVING POWER (lines/mm - H or L) [†]	MTF (lines/mm at 10%)
2402	Panchromatic Negative	80*	100 - H 50 - L	140 (D-19)
2424	Infrared Negative	100*	100 - H 32 - L	85 (EA-5)
2443	Infrared False Color	10*	63 - H 32 - L	60 (D-19)
SO-356(2483)	Ektachrome	16	200 - H 100 - L	140 (E-4)
PAN-X	Panchromatic Negative	32	160-- H	-
TRI-X	Panchromatic Negative	250	80 - H	-

* Aerial Exposure Index (not related to ASA)

† H - Test Object Contrast 1000:1, L - Test Object Contrast 1.6:1

Δ Sources for data: Kodak Publications - M-29 Aerial Photography
P-302 Photomicrographic Data
M-61 Kodak Aerial Films and Photographic Plates
P-9 Kodak Plates and Films for Science and Industry
AF-13 Kodak Black and White Films in Rolls

were also listed for comparison. For films used in aerial photography, the film speed is given in terms of the Aerial Exposure Index (AEI) or the Aerial Film Speed (AFS) instead of the ASA index which is usually published for films employed in pictorial photography. A different criterion for speed is required in aerial photography because small changes in luminosity must be detected from ground reflections viewed from altitudes of 50,000 to 100,000 feet sometimes through less than ideal atmospheric conditions. As a result, aerial films are usually exposed and developed for high contrast response, and changes in the slope of the D-Log E characteristic curves become very important in determining the quality of the scene which is photographed. Both the ASA and the AEI and ASF speeds are specified for carefully controlled processing conditions, and the details of their determination are discussed in ANSI bulletins PH 2.34-1969 and PH 2.5-1972.

For comparison, the resolution and approximate ASA speed of some state-of-the-art incoherent-to-coherent image devices are given in Table 3. The equivalent ASA speed parameters were calculated from published sensitivity data [1-4] which can be expected to improve as more sensitive photoconductive materials are developed. It can be seen, however, that the speeds of these devices are much lower than those of the better aerial films, even though their resolving powers are almost competitive. If image intensifiers are employed to overcome the lack of sensitivity of the incoherent-to-coherent converters, the resolution is degraded to the point of being unsatisfactory for high altitude aerial evaluation. A typical CRT system would, for example, provide a 500-2000 line display, whereas a resolution of 6,000 to 14,000 lines is possible with 70 mm aerial film.

The maximum ground resolution of the 70 mm aerial photographs can be calculated from the data of Tables 1 and 2. This calculation is presented in graphical form in Figure 1. The spread in maximum resolution possible for the six 70 mm films is about 7.5 to 24 feet. It should be emphasized that the actual resolution obtainable is highly dependent on the quality of the camera's optical system, and the exposure and processing conditions. Microscopic analysis of enlarged prints obtained from each of the six

Table III. Photographic Characteristics of Incoherent-to-Coherent Imaging Devices

Device	Sensitivity (ergs/cm ²)	Resolution (lines/mm)	Write Wavelength (Å)	Equivalent ASA
PROM (ITEK)	1	100	4330	0.5
OTTO (HUGHES)	5	70	White	6
PHOTOTITUS (PHILLIPS)	100	40	White	0.3
FERPIC (BELL LABS)	10 ⁴	40	White	0.003

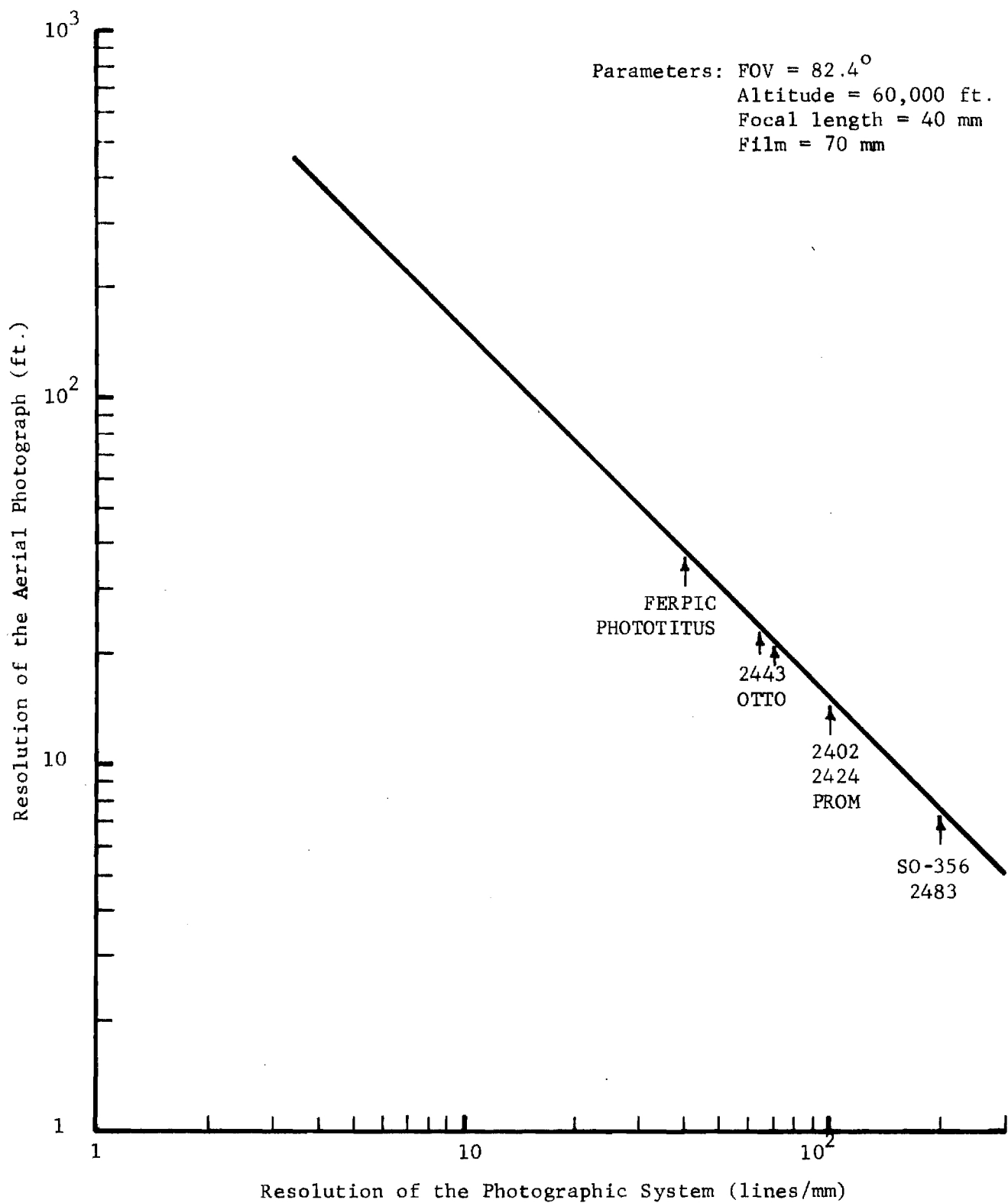


Figure 1. Maximum Calculated Resolution of the 70 mm Aerial Film.

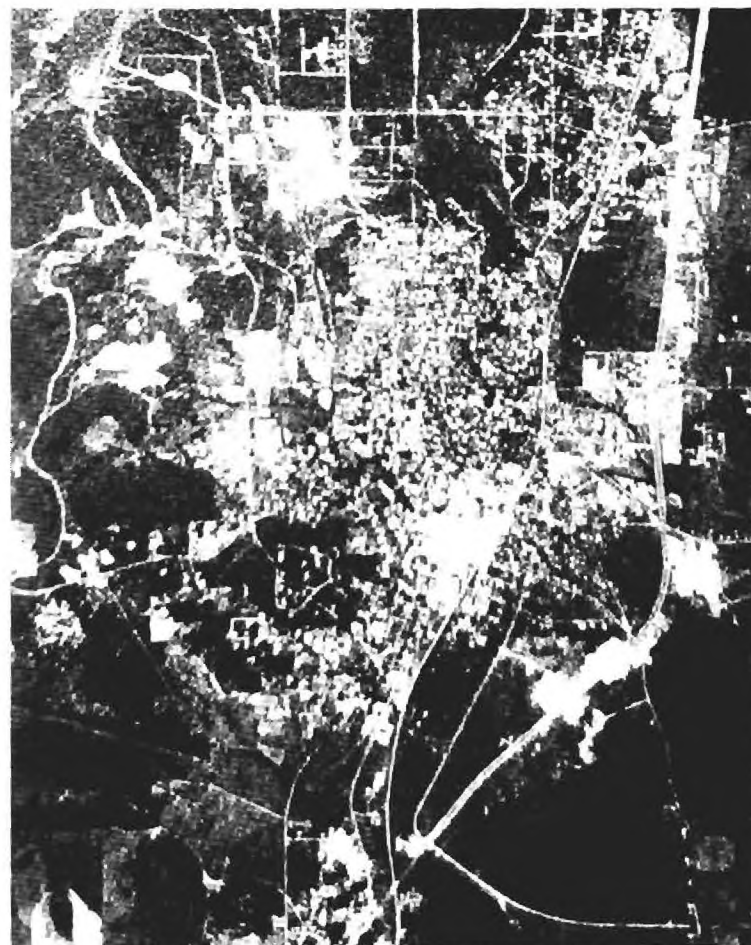
films revealed much lower resolution values than those predicted from Figure 1. Figures 2 and 3 show 19 77 times enlargements of the SO-356 70 mm film compared to the same area on the ground obtained from enlargements of a positive transparency of a 7.5 inch square color infrared aerial plate on unknown emulsion. Both enlargements cover an area of approximately 13,600 ft. x 17,000 ft. on the ground. Although the subjective resolution of the 7.5 inch square plate as determined by microscopic examination was somewhat greater than that of the 70 mm film, the graininess of the later made its apparent resolution appear much worse. The graininess was apparently a result of the high contrast exposure and the subsequent developing process. It was also noted that the exposure, and hence the resolution, varied from the center to the edges of the 70 mm film. This effect could have been caused by the 40 mm wide angle lens. The subjective resolution appeared to be about 15-20 feet for the 7.5 inch square plate, and about 25-30 feet for the 70 mm film. Some loss of resolution and part of the exposure problem could have been a result of the copying process.

Although the quality of the 70 mm aerial film was not as good as one could have hoped for, it was decided to proceed with the optical analysis of this film since MSFC had obtained ground truth data on forestry classification for areas around Huntsville, Alabama and Redstone Arsenal covered by these photographs. It was also recognized that the available spatial information on any aerial photograph taken at an altitude of 60,000 feet would consist primarily of patterns of growth rather than individual tree signatures in view of the limitations imposed by the maximum film resolution. The spatial content of forestry images will also be highly dependent on the season in which the photographs are obtained. During the winter season, the absence of foliage on the deciduous trees should result in changes in spectral and spatial signature which will enhance their classification by optical processing. The 70 mm photographs supplied by MSFC were taken in May, and no enhancement is expected since deciduous trees in the Southeast have usually developed full foliage by this time.

The relationship between the Fourier transform light distribution and the spatial features of the object are also an important system consideration.



(a) 7.5 inch Square. Color 1R.



(b) 70mm - S0 356.

Figure 2. Comparison of Two Aerial Photographs of an Urban Area (13,600 x 17,000 ft.).



(a) 70mm - SO 356.



(b) 7.5 inch Square. Color 1R.

Figure 3. Comparison of Two Aerial Photographs of Rural Areas (13,600 x 17,000 ft.).

The geometry of the Fourier transform processor is shown in Figure 4. The separation of adjacent maxima of a Fourier transform diffraction pattern corresponding to an object feature of dimension ΔX_0 is approximately $\Delta X_1 = \lambda f / \Delta X_0$, where λ is the optical wavelength, and f is the focal length of the Fourier transform lens. The optical processor used in this study employed an argon ion laser source operating on the 488 nm transition, and a Fourier transform lens of 59.89 cm focal length. Setting ΔX_1 equal to the radius of the fiber optic bundle (0.505 in.), the smallest feature which would result in at least one secondary maximum falling on the fiber optic array was found to be 0.023 mm, corresponding to a linear dimension of approximately 30 feet on the ground area covered by the 80 degree FOV from an altitude of 60,000 feet.

The focal length of this lens, which is a highly corrected Fourier transform lens with 488 nm antireflection coatings, is not optimum for the diameter of the fiber optic bundle and the resolution of the image transparency. A focal length of 30 cm would accommodate an image resolution of about 15 feet, and would provide at least three maxima in the diffraction pattern for the measured resolution of the 70 mm aerial photographs. It was, however, necessary to use the existing Fourier transform lens because of the importance of the antireflection coatings in reducing the background light distribution in the diffraction plane. Measurements performed late in the program showed that the transform lens had not been properly coated, and that improved antireflection performance could be obtained by using a helium neon laser at 632.8 nm wavelength. Unfortunately, the highest power helium neon laser available was not compatible with the sensitivity requirements of the fiber optic detector system.

An alternative detector array was also investigated during the course of the program. This detector, a Recognition Systems Inc. Model WRD-6400, consisted of a planar silicon ring and wedge array which would have made a low resolution analysis of the aerial photographs possible early in the program while the electronic system for the fiber optics detector was being conceived. Tests were performed using a series of ruled gratings as

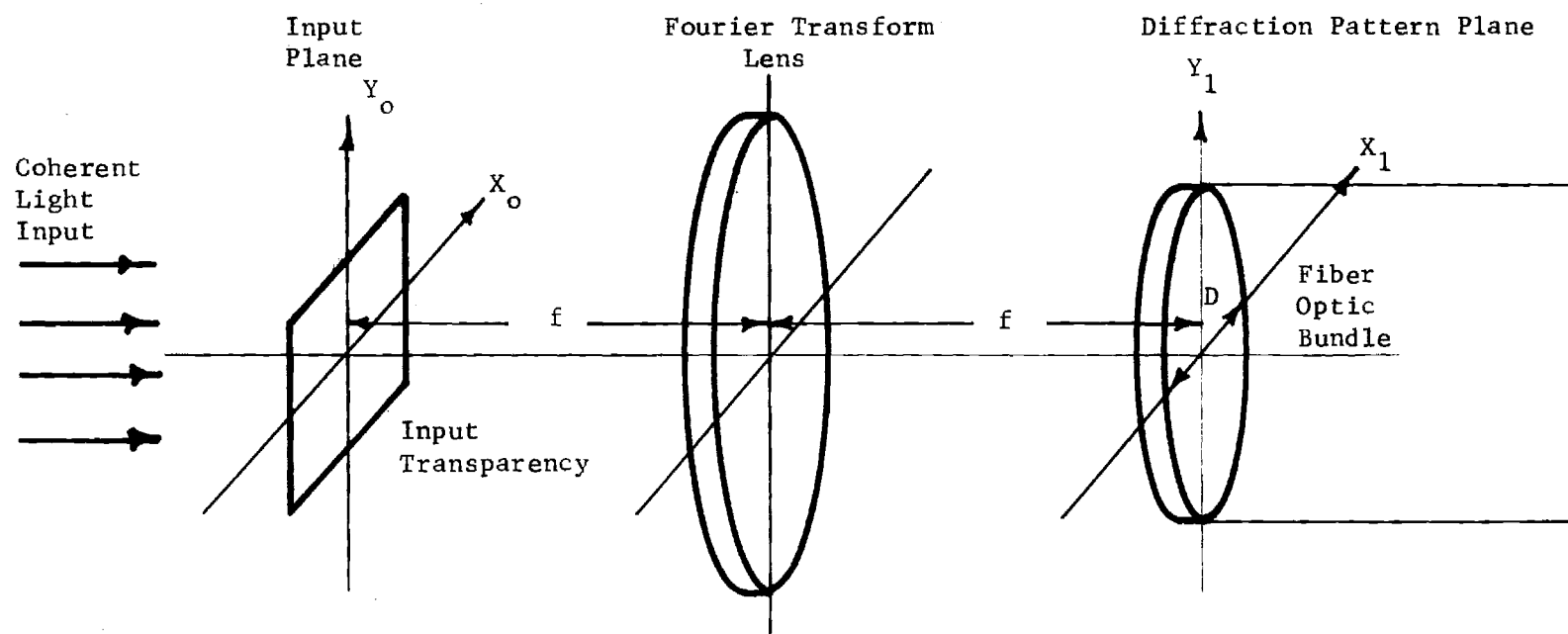


Figure 4. Geometry of the Fourier Transform Optical Processor.

objects to determine the sensitivity and isolation of the array. It was found that the halation effect resulting from scattering of the glass window interfaces limited the dynamic range of this detector system to about 15 dB. It was decided that no useful information concerning the spatial information contained in low contrast aerial forestry images could be obtained with this system. A new RSI detector system, which is not supposed to have the halation problem was ordered, but the order was cancelled after 8 months because RSI was unable to assure delivery.

The third major system consideration involved the conception of effective algorithms for pattern recognition. Since it was not possible apriori to determine the form of the spatial signatures from forestry images, the initial software design goals were focused on providing flexible output data formats, and enhancing the signal-to-noise ratio of the diffraction pattern. To accomplish these goals, both linear and log outputs were provided on variable sampling intervals ranging from a single channel to the entire 169 channels of the detector array. In addition, provisions were made to subtract the background intensity distribution from the diffraction pattern and print out either the corrected or uncorrected values. The details of computer programs required to accomplish these processing operations are described in Section IV of this report.

It was initially planned that analysis of the Fourier transform diffraction patterns of forestry images would be employed as a basis for generating first order algorithms for signature analysis which could be further refined in iterative steps. Difficulties experienced with achieving the hardware performance goals did not, however, leave enough time for this plan to be pursued. Data obtained during the program was found to be useful in generating guidelines for developing pattern recognition algorithms, and these recommendations will be discussed in Section VI of this report.

III. FIBER OPTIC DETECTOR

The diffraction pattern sampling geometry was determined by the configuration of the concentric ring fiber optic detector array which was chosen as the system detector interface. This array, which was designed and fabricated at EES/Georgia Tech under contract NAS8-28215, consisted of a fiber optic bundle containing approximately 89,000 3 mil optical fibers which were sorted into 168 concentric rings about a single central fiber. On one end of the bundle the fibers were bonded together and polished to a smooth planar surface. The fibers on the end opposite the trunk were sorted into 169 smaller bundles, one for each ring, with the number of fibers per bundle ranging from 1 for the center fiber to approximately 1,060 fibers for the outer ring.

The design concept was to terminate each fiber bundle with a photodetector, and to sample the photodetector outputs with a high speed multiplexer. A preliminary design for the electronic circuitry required to carry out this concept was performed on contract NAS8-28215, but the implementation of the electronic interface was not included in this program. The final design of the electronic interface and the fabrication of the photodiode array was a major part of this program. The details of the fabrication of the photodiode housing and the performance of the detector array are discussed below.

A. Fabrication Details

To accommodate and align the 169 fiber bundles with the mating photodiodes, a rectangular array of holes of varying diameter was drilled in the mounting plate of the fiber optic detector housing. The diameter of each hole was selected such that the fiber bundle would just fit without compression. The bundles were pulled through the holes from the inside and the bundle lengths adjusted to remove any strains or sharp bends. An epoxy adhesive was then applied to the inside of the mounting plate and the bundles were worked in and out until the epoxy filled the hole. Finally, the bundle was cut with a razor blade flush with the outside surface of the mounting plate. A photograph of the inside of the fiber optic detector housing is shown in Figure 5, and a photograph of the face of the detector with every eleventh ring illuminated from the mounting plate side is shown in Figure 6.

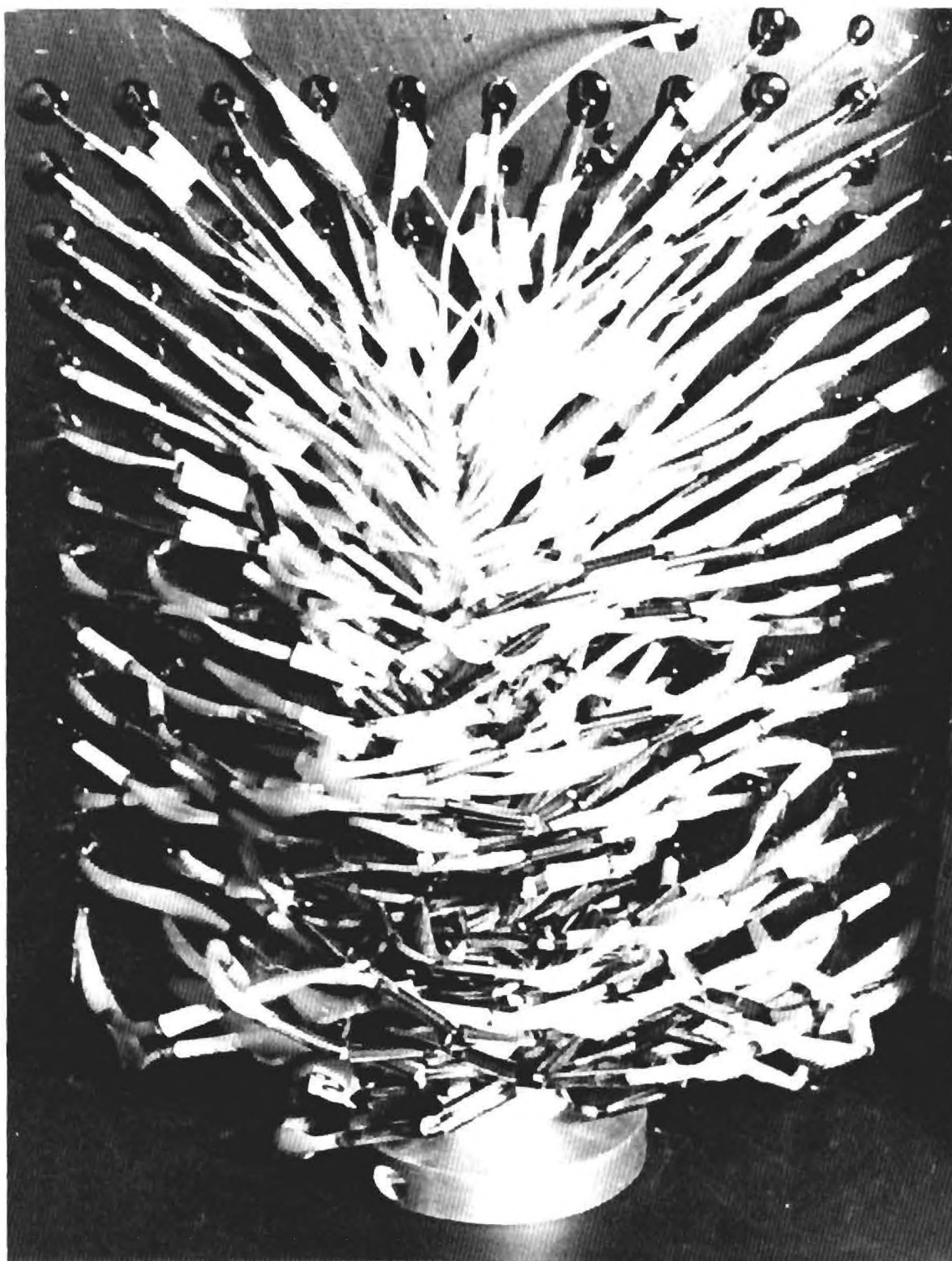


Figure 5. Fiber Optic Detector Housing.

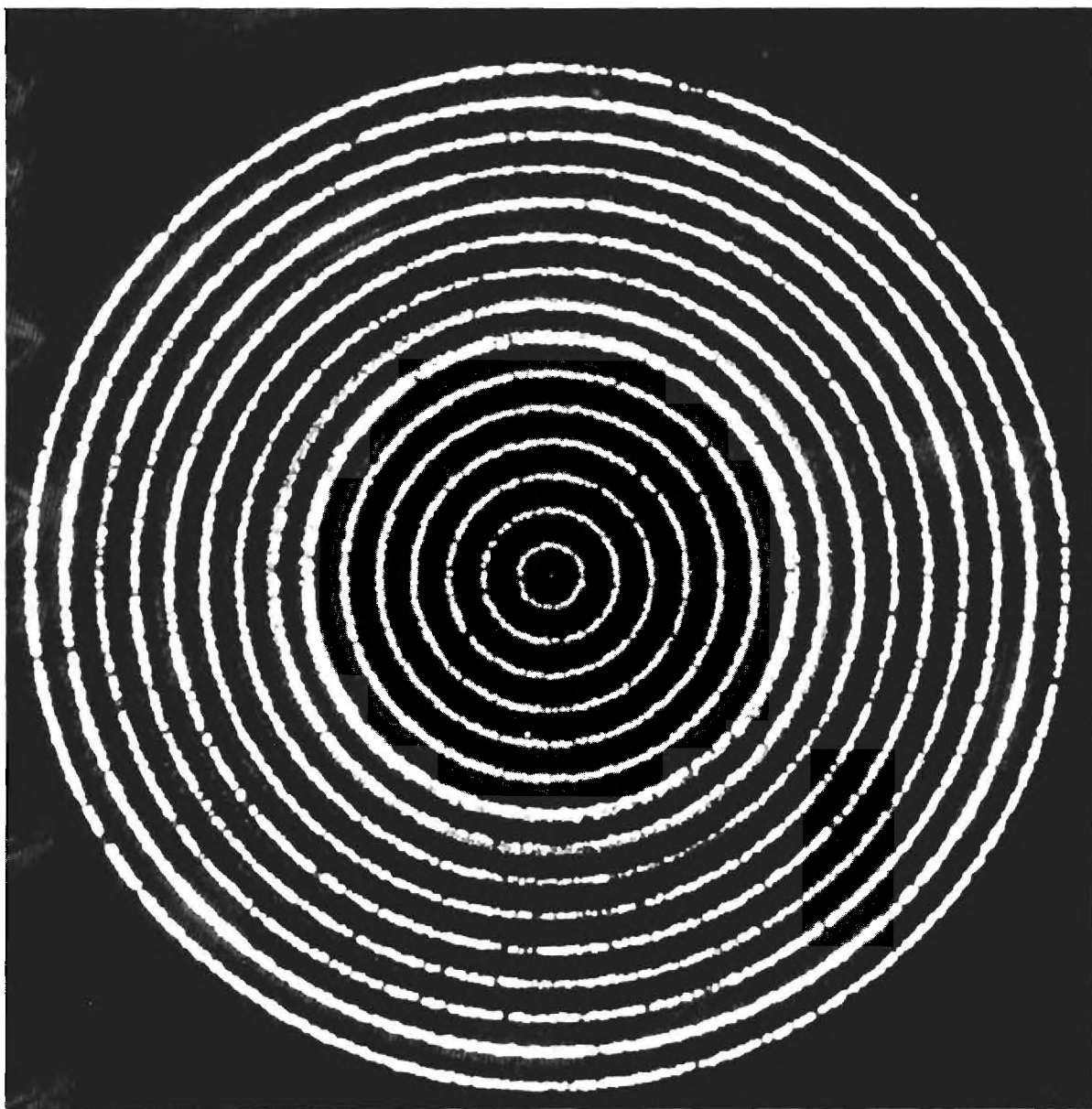


Figure 6. Face of the Fiber Optic Array with Every Eleventh Ring Illuminated on the Mounting Plate.

Correspondence of the ring locations on the face of the array with the locations of the bundle ends on the mounting plate is shown in the layout of Table IV. The rings are assigned numbers in order of increasing radius from the center fiber (ring number 0) to the outer ring (ring number 168). The bundle ends are arranged in a rectangular matrix consisting of 11 columns and 16 rows on the mounting plate. The photodiodes are mounted in a plate with a matching hole pattern as shown in the photograph of Figure 7. Photodiodes with three different active areas were employed, and their assignment to the fiber optic bundles is listed in Table V. The active areas of the photodiodes were selected to be slightly larger than the largest diameter of the fiber bundles to which they were assigned because of the 70 degree radiation beamwidth of the fibers, and the unavoidable separation of the bundle end and the active element of the diode resulting from the diode's mounting configuration. It will be shown in Section V that larger area diodes would have been desirable had they not been economically prohibitive.

In operation, the two mounting plates are placed in contact, and held in proper alignment by machine screws located on the sides of the electronic interface assembly. This assembly will be discussed in detail in Section IV.

B. Performance

The sampling characteristic of the fiber optic array may be discussed in terms of the power output from each ring of fibers resulting from illumination of the face of the array with a uniform light distribution. This radial distribution function is given by the approximation

$$P(n) \approx 2\pi n I_o A_f L_f L_c, \quad (1)$$

where $P(n)$ is the power out of the fiber bundle terminating ring number n ,

I_o is the input light irradiance at the face of the fiber bundle expressed in w/cm^2 (constant over all 169 rings),

A_f is the area of a single 3 mil optical fiber,

L_f is the transmission loss through the length of the fiber,

L_c is the coupling loss at two air-fiber interfaces, and

$2\pi n$ is the number of fibers in ring number n .

Table IV. Fiber Optic Array Layout - Ring Number
vs. Row and Column on Mounting Plate.

Column No. Row No.	1	2	3	4	5	6	7	8	9	10	11
1	158	159	160	161	162	163	614	165	166	167	168
2	147	148	149	150	151	152	153	154	155	156	157
3	136	137	138	139	140	141	142	143	144	145	146
4	125	126	127	128	129	130	131	132	133	134	135
5	114	115	116	117	118	119	120	121	122	123	124
6	103	104	105	106	107	108	109	110	111	112	113
7	92	93	94	95	96	97	98	99	100	101	102
8	81	82	83	84	85	86	87	88	89	80	91
9	70	71	72	73	74	75	76	77	78	79	80
10	59	60	61	62	63	64	65	66	67	68	69
11	48	49	50	51	52	53	54	55	56	57	58
12	37	38	39	40	41	42	43	44	45	46	47
13	26	27	28	29	30	31	32	33	34	35	36
14	15	16	17	18	19	20	21	22	23	24	25
15	4	5	6	7	8	9	10	11	12	13	14
16								Center	1	2	3

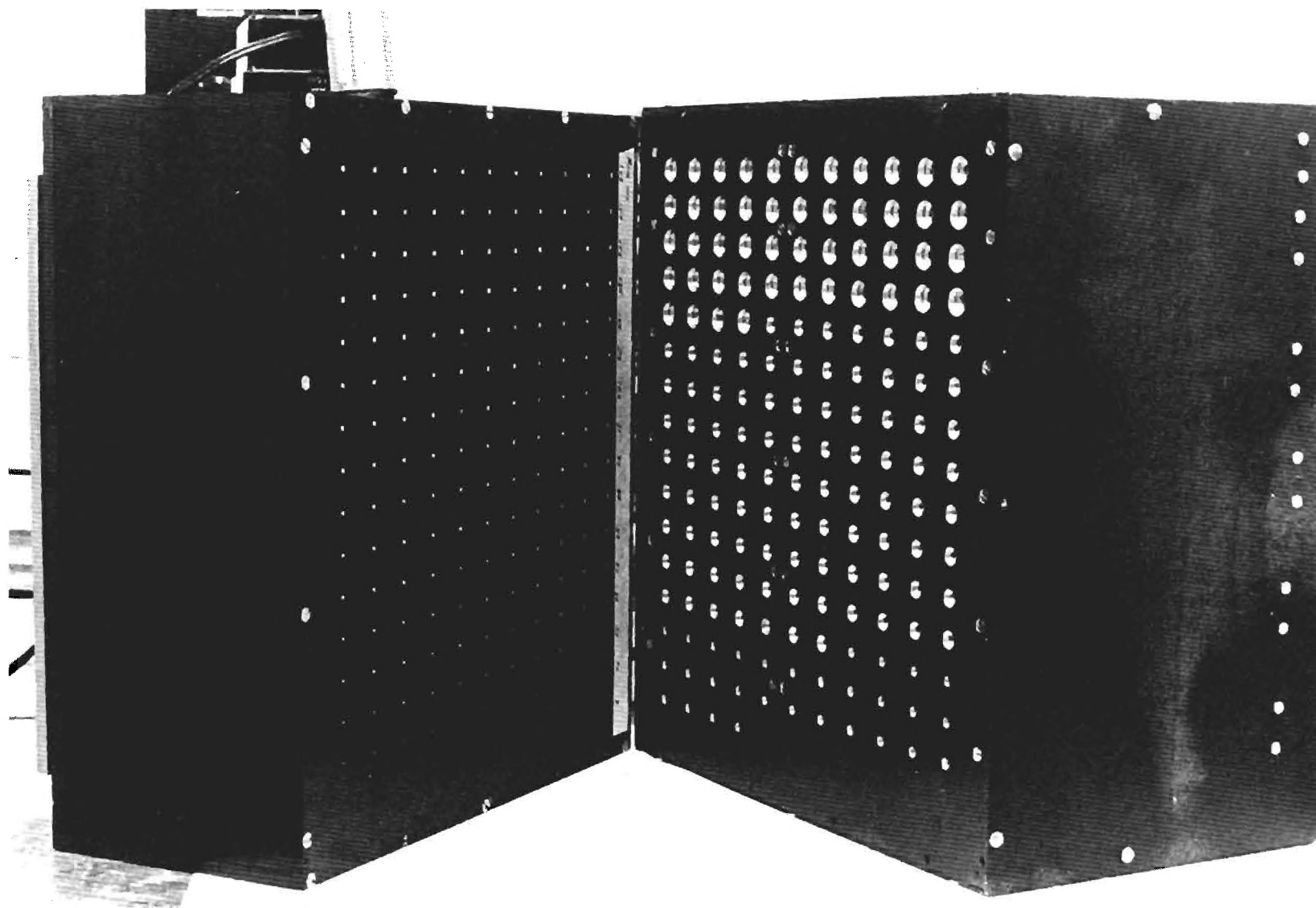


Figure 7. Photograph of the Fiber Optic and Photodiode Mounting Plates.

Table V. Photodiode Characteristics

Diode Type	Ring Number Assignment	Maximum Bundle Diameter (cm ²)	Active Area (cm ²)	Sensitivity (volts/ μ watt)
UDT - 3DP	0 - 31	0.011	0.032	0.269
UDT - 5DP	32 - 121	0.044	0.051	0.284
UDT - 6DP	122 - 168	0.061	0.203	0.235

The applicable parameters for the fiber optic detector were:

$$A_f = 4.56 \times 10^{-5} \text{ cm}^2$$

$$L_f = 0.71 \text{ (1 dB/ft} \times 1.5 \text{ ft)}$$

$$L_c = 0.64$$

$$P(n) = 3.65 \times 10^{-7} n \quad (2)$$

The measured characteristic and the calculated characteristic predicted by eqn. (2) are shown in Figure 8. Two illumination sources, one incoherent and the other coherent were employed with identical results. The first distribution was achieved by illuminating a ground glass plate with light from a tungsten lamp, and the variation across the fiber optic detector face was found to be less than 0.5 percent with this configuration. An expanded and spatially filtered argon laser beam was also used to illuminate the ground glass and the resulting light distribution was found to be as uniform as that obtained with the tungsten source. Except for a constant loss factor, good agreement exists between the two curves over most of the detector face; however, the significant departure of the measured points for rings 2 and 3 from the calculated curve strongly suggested that damage had probably occurred to these fiber bundles during the mounting operation. A microscopic analysis of the light distribution on the face of the bundle resulting from illumination of the bundle end array confirmed this suspicion. Figures 9A, 9B, and 9C show photographic enlargements of the light distribution resulting from illumination of one column at a time on the fiber bundle mounting plate containing the fiber bundles connected to rings number 2, 3 and 4. These photographs reveal the individual active fibers in each ring for which light is coupled into the corresponding bundle end. By illuminating one column at a time on the mounting plate, every eleventh ring of the distribution is activated. Missing active fiber locations can be observed for each activated ring of the array, and the resulting variation in active area probably accounts for the variations in the measured radial intensity distribution of Figure 8. It can also be seen that rings 2 and 3 have proportionally many more missing fibers than ring 4 thus accounting for the large observed departures of the measured curve from the calculated curve.

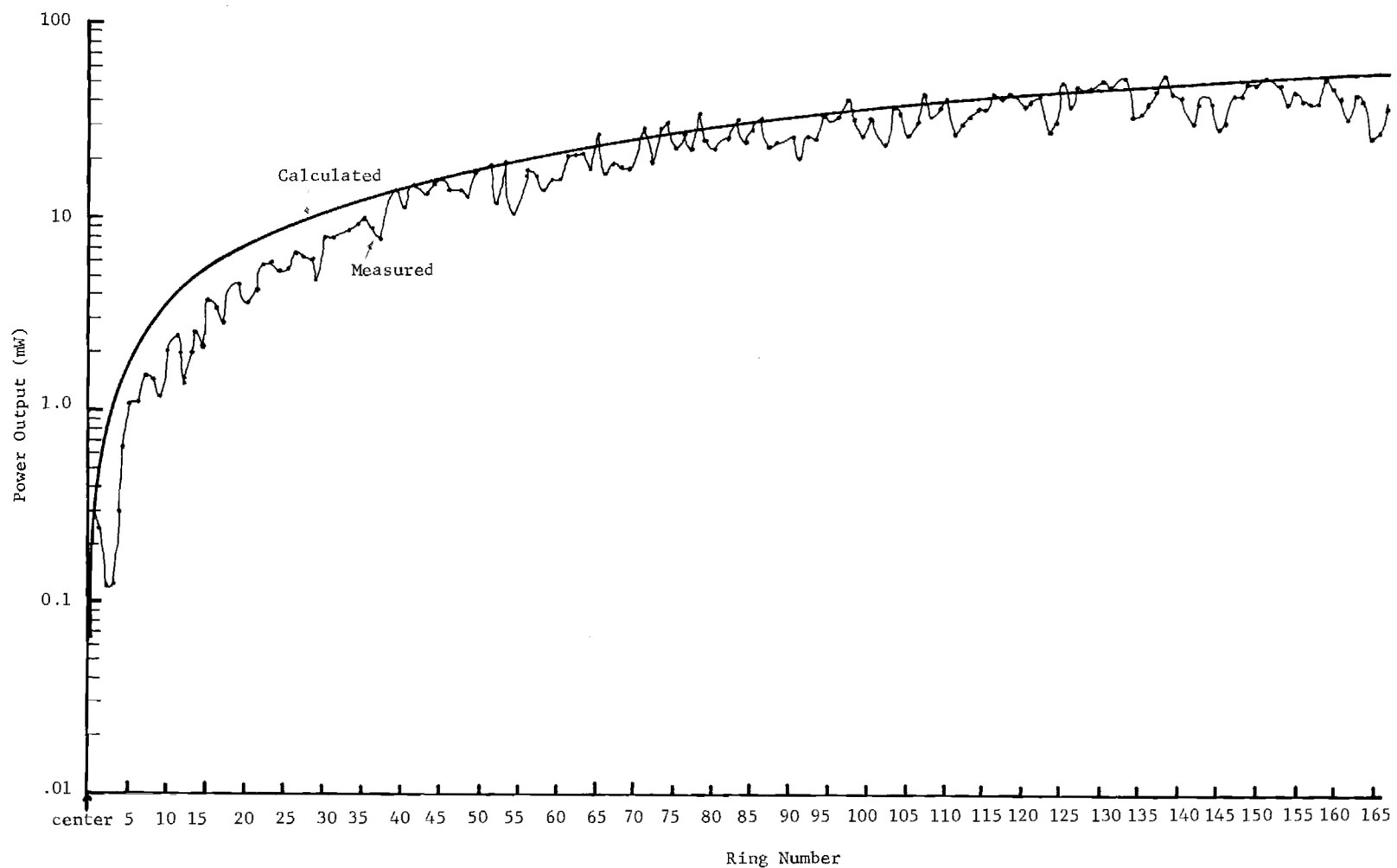


Figure 8. Radial Distribution of Fiber Optic Detector Power Output for Uniform Illumination.

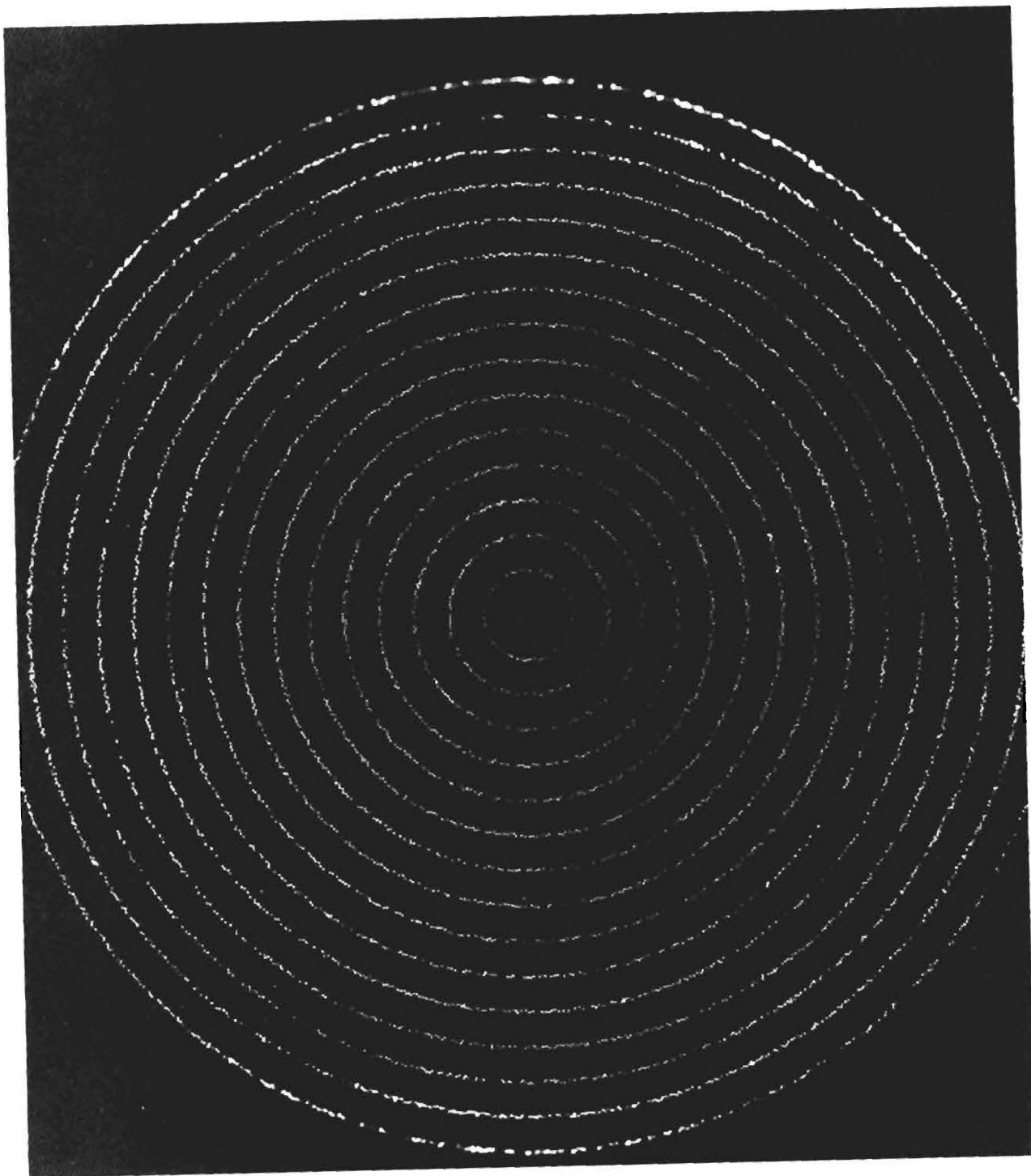


Figure 9A. Fiber Optic Array Light Distribution Resulting From Illumination of Column 10 in the Fiber Bundle Mounting Plate.

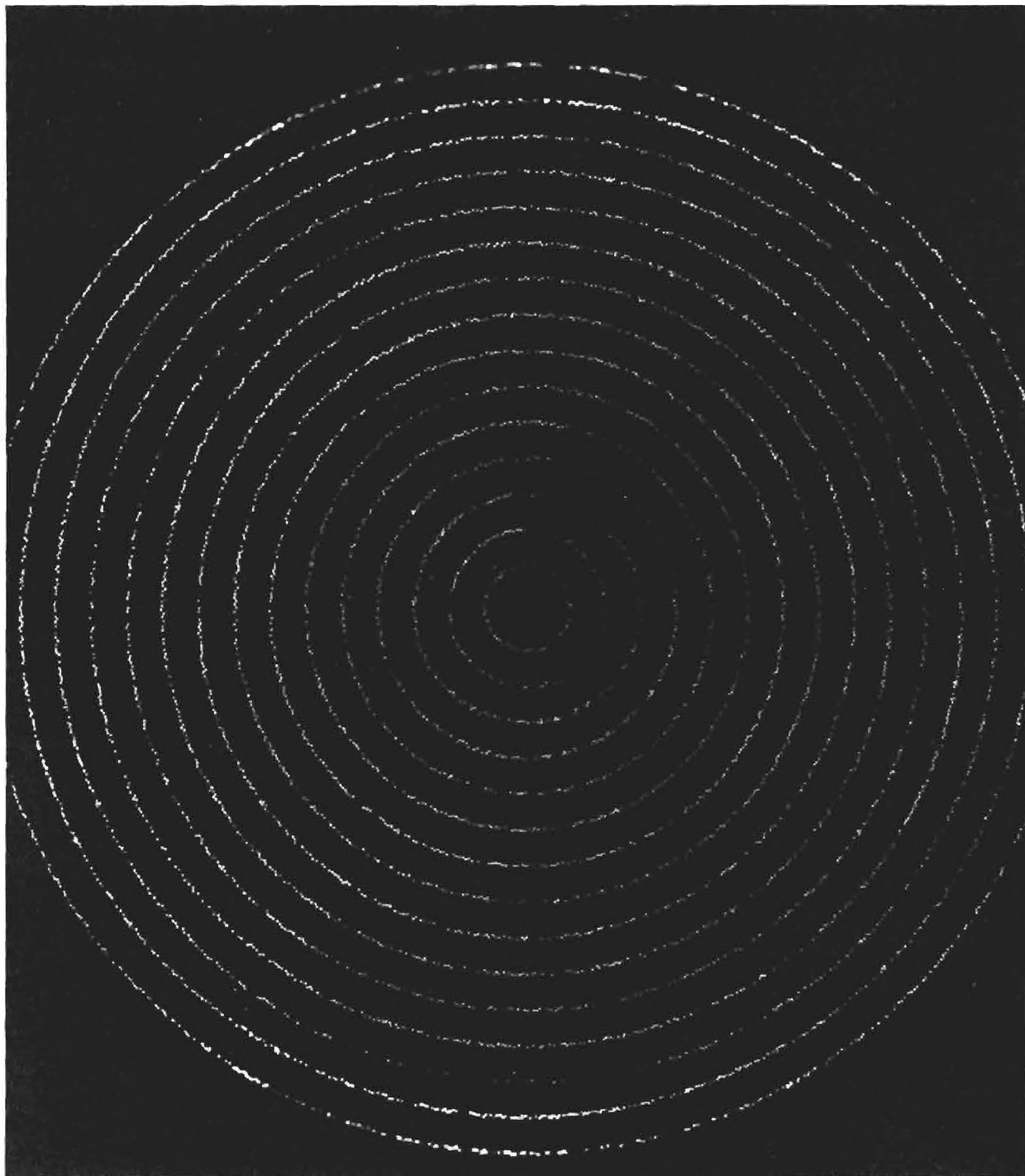


Figure 9B. Fiber Optic Array Light Distribution Resulting From Illumination of Column 11 on the Fiber Bundle Mounting Plate.

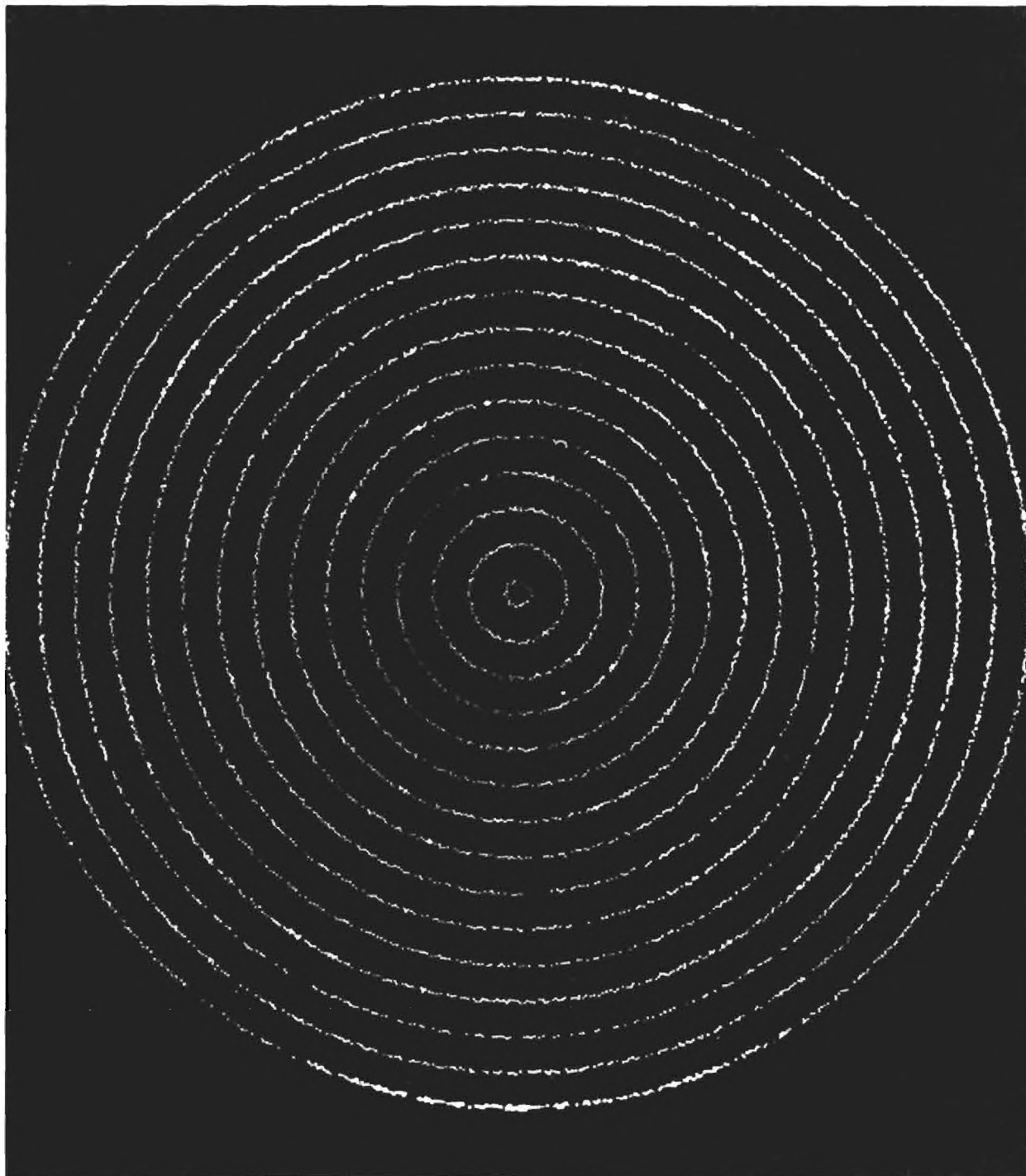


Figure 9C. Fiber Optic Array Light Distribution Resulting from Illumination of Column 1 on the Fiber Bundle Mounting Plate.

During this observation it was also discovered that some bundles contained one or more stray fibers belonging to another ring. These strays were traced and removed by illuminating one bundle at a time and locating the ring to which the stray belonged. None of the irregularities discovered during the testing phase caused undue concern since the fiber optic detector characteristic, once known, can be smoothed out during the digital processing operations.

IV. OPTICAL/ELECTRONIC INTERFACE

The electronic portion of the Fourier transform detector provides the interface between the fiber optics array, consisting of a central fiber and bundles from 168 concentric rings, and a digital data processing system. The electronic system consists of (1) the photodiodes, (2) a current-to-voltage converter for each of the photodiodes, (3) an electronic commutating system, (4) a sample-and-hold circuit and an analog-to-digital converter. The digital processing system consists of a computer interface, a digital processor, and a data display system.

The photodiodes are mounted in a metal plate which is placed in contact with a similar plate in which the fiber optic bundles are terminated. The diodes are arranged in sixteen rows, the sixteenth row containing four diodes, and the remaining fifteen rows containing eleven diodes each. Figure 10 is a photograph of the photodiode mounting plate showing this layout. As described in Section III, three sizes of diodes are used. The central fiber and the first thirty rings are terminated with PIN-3DP photodiodes (United Detector Technology, Inc.). Rings numbered 31 through 121 are terminated in PIN-5DP photodiodes, and the remaining 46 rings are terminated in PIN-6DP photodiodes. A photograph of the arrangement of the photodiodes and the circuit boards is shown in Figure 10.

Each photodiode provides the input to a current-to-voltage converter. A converter consists of one-half of a μ A747 operational amplifier. The converters have a conversion ratio of $1\text{V}/\mu\text{AMP}$. One hundred and sixty-nine of the current-to-voltage converters are required--one for each photodiode. These converters are located on six printed circuit boards mounted just above the photodiodes.

The outputs of the current-to-voltage converters are connected to the inputs of six high level multiplexers (HP-12751A) in a Hewlett-Packard 2313B analog-to-digital interface subsystem. Each of the six high level multiplexers provides for 32 single ended inputs, giving a total input capability for the six boards of 192 channels. Only nine channels are used on the last board.

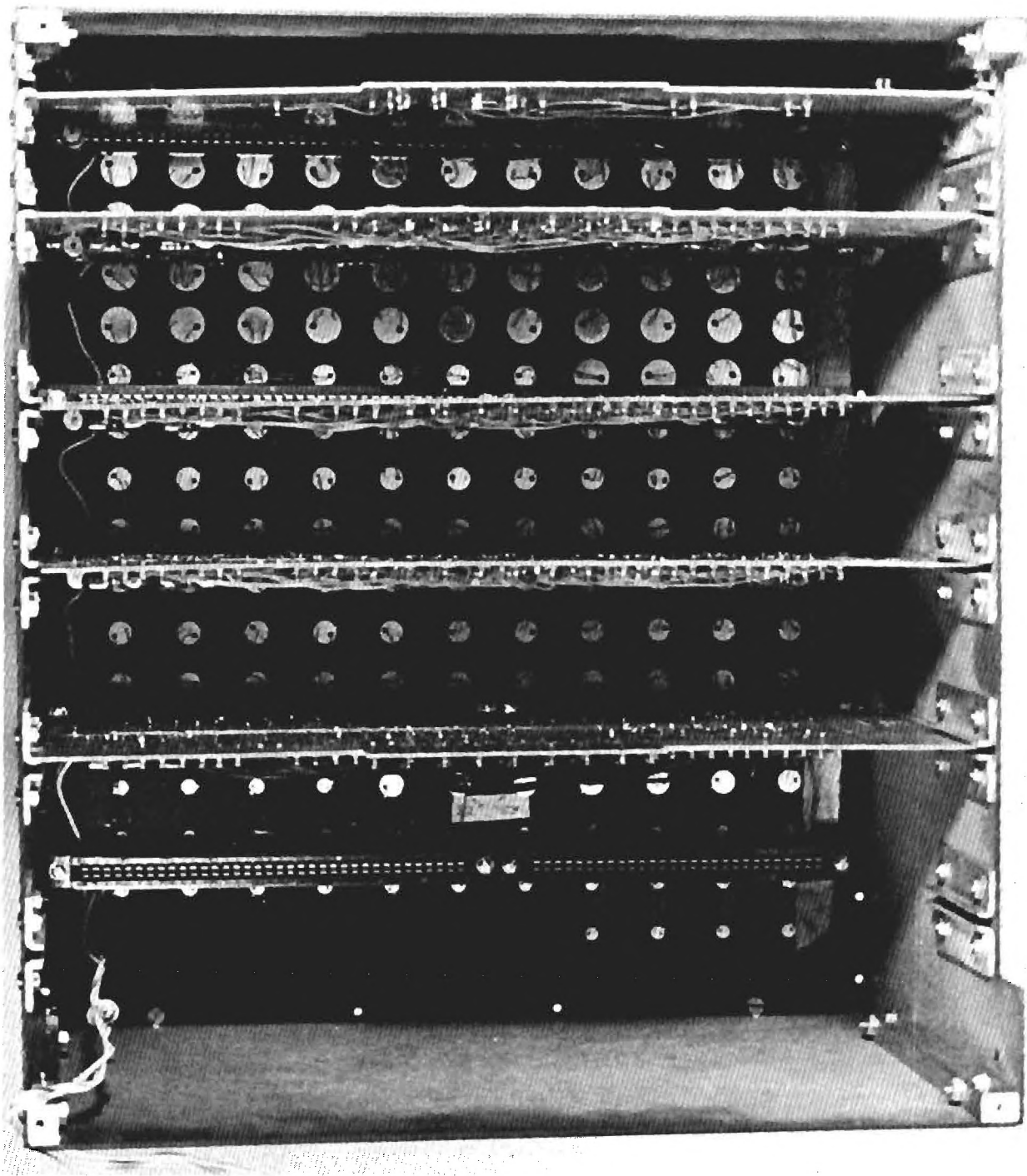


Figure 10. Arrangement of Photodiodes and Circuit Boards.

The sample-and-hold amplifiers and analog-to-digital converter are contained in the 2313B subsystem. The analog-to-digital converter is a 12 bit converter which gives 4096 quantization levels over an input voltage range of -10.24 to 10.235 volts in 5 millivolt steps.

The interface with a Hewlett-Packard 2100 series digital computer is provided by an interface board in the 2313B subsystem and an interface board in an input-output slot in the computer.

The 2100 series computer provides the means of reading the data from the 2313B subsystem, performing processing of the data to get it into the proper form for the various display capabilities, and outputting the data to either a teletype for hard copy recording or to an oscilloscope for real time display purposes.

A. Subsystems Description

A block diagram of the electronic system is shown in Figure 11. The heart of the system is a Hewlett-Packard 2100 series computer which has input commands entered and responds in an interactive mode via a teletype terminal. The computer operates the 2313B subsystem which commutates the 169 analog input channels. It also outputs the processed data to an oscilloscope which provides a visual display of the spatial frequency data, or provides for printing of the data by means of a teletype-terminal.

The photodiodes are connected to the input channels of the 2313B subsystem by means of current-to-voltage converters. A schematic diagram of two of the 169 current-to-voltage converters is shown in Figure 12. Each of the converters make use of one-half of a μ A747 operational amplifier.

The input voltage range of the analog-to-digital converter in the Hewlett-Packard 2313B subsystem is -10.24 to 10.235 volts. To make use of the full range of the converter, the zero light value must be offset to the most positive output voltage of the current-to-voltage converters. The cathode of the photodetector is grounded, and hence increasing light intensity drives the output of the current-to-voltage converters in a negative direction. Maximum light intensity is that which results in a negative input voltage to the analog-to-digital converter which is equal to -10.24V.

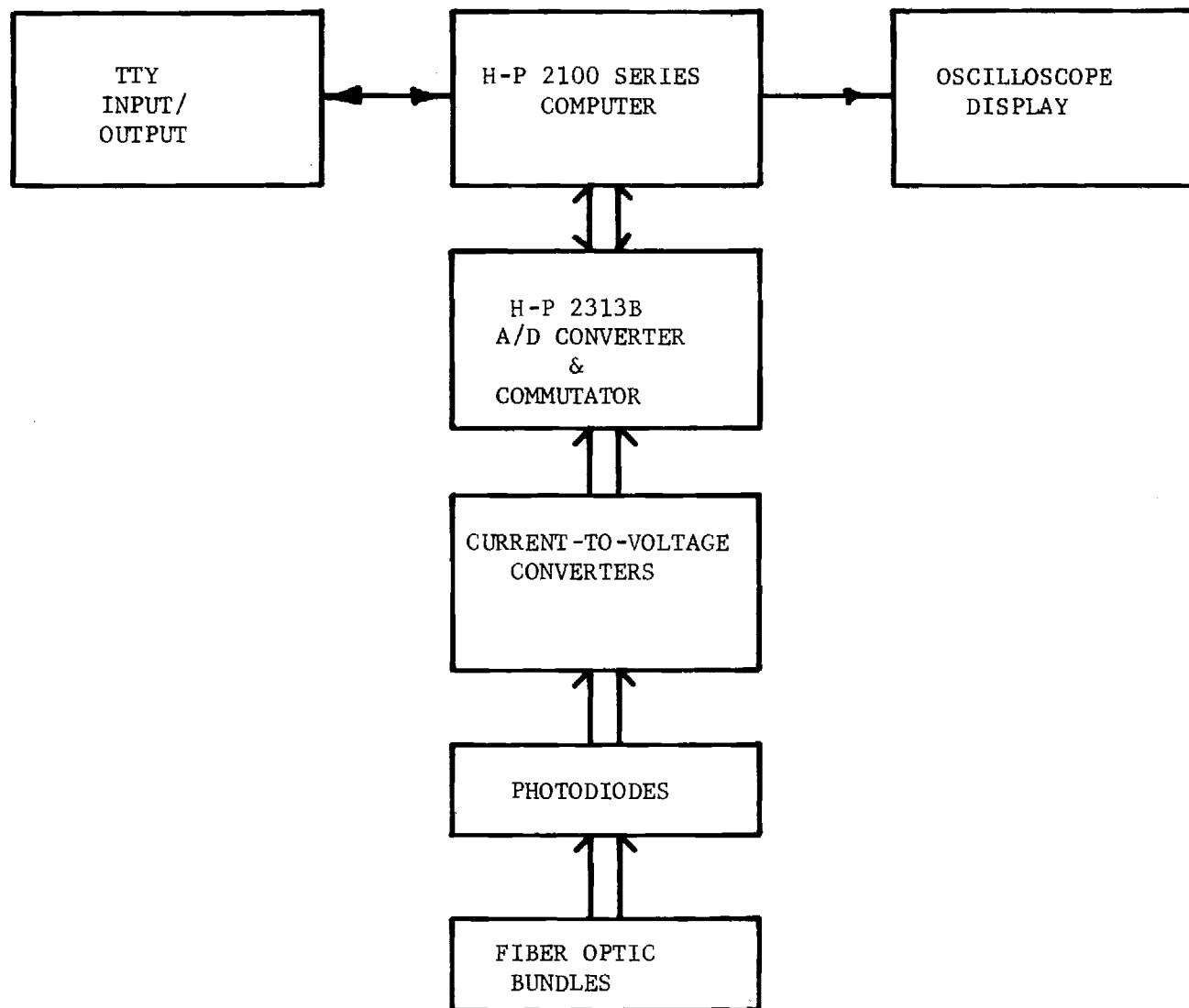


Figure 11. Block Diagram of Optical Processor Electronic System.

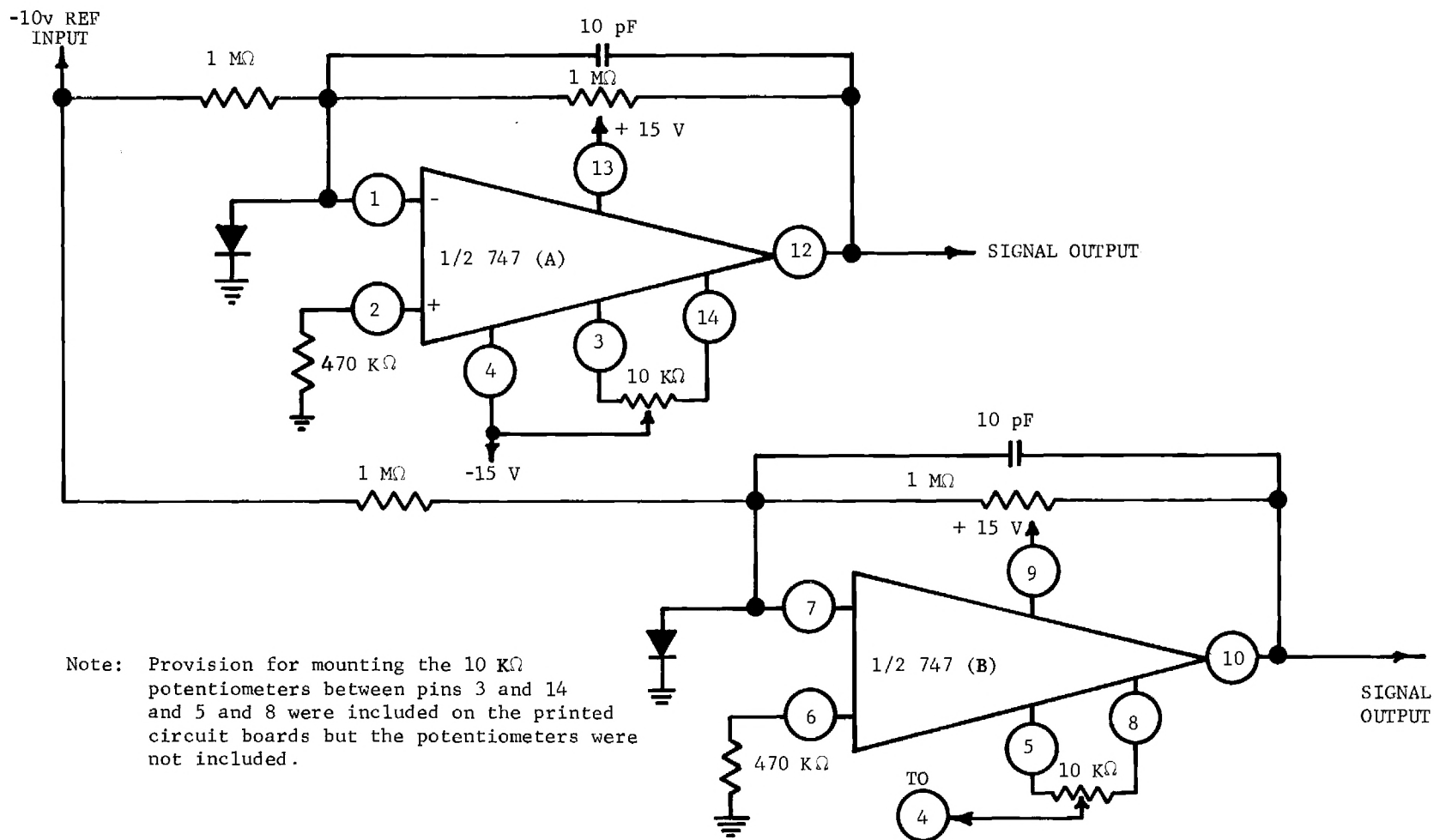


Figure 12. Schematic Diagram of a Dual Current-to-Voltage Converter.

To offset the output voltage of the current-to-voltage converters in this manner an input reference voltage is summed into the input of the converters as shown in Figure 12. The source of this stable reference voltage is shown in the schematic diagram of the reference voltage supply (Figure 13). The reference supply uses a temperature stabilized zener diode and an operational amplifier to supply the nominal -10 volt reference required. Only one reference supply is used and it is located on circuit board number one. All the other five circuit boards receive their reference supply from this source.

A photograph of one of the circuit boards is shown in Figure 14. To provide the interface between the rows of photodiodes, containing eleven diodes per row, and the input to the 2313B multiplexer cards, which have thirty-two single ended inputs per card, a single circuit board design requiring space for thirty-eight operational amplifiers (nineteen packages) was provided on each circuit board. Only those amplifiers needed for a specific board were mounted on the particular circuit board. Hence, each of the six circuit boards were made alike, but each has a different arrangement of components and a different jumper arrangement.

The photodiodes are connected to the circuit boards through a 56 and a 72 contact printed circuit connector for each circuit board, and the circuit board plugs into these connectors which are mounted end to end. On the top of each circuit board are the printed circuit contacts to mate with a 48 contact printed circuit connector which connects the current-to-voltage converter outputs to the inputs of the high level commutators in the 2313B subsystem. The cables which are used to interconnect the current-to-voltage converters and the 2313B contain 32 miniature coaxial cables and are wired so that each channel is connected in the same order in each connector. Each of the cables are wired alike.

Visible in the photograph of Figure 5 are the printed circuit contacts which mate with the 72 contact connector on the left and the 56 contact connector on the right. The reference supply is the circuit nearest the right edge of the board (present only on circuit board number one). The rest of the integrated circuit packages are the current-to-voltage

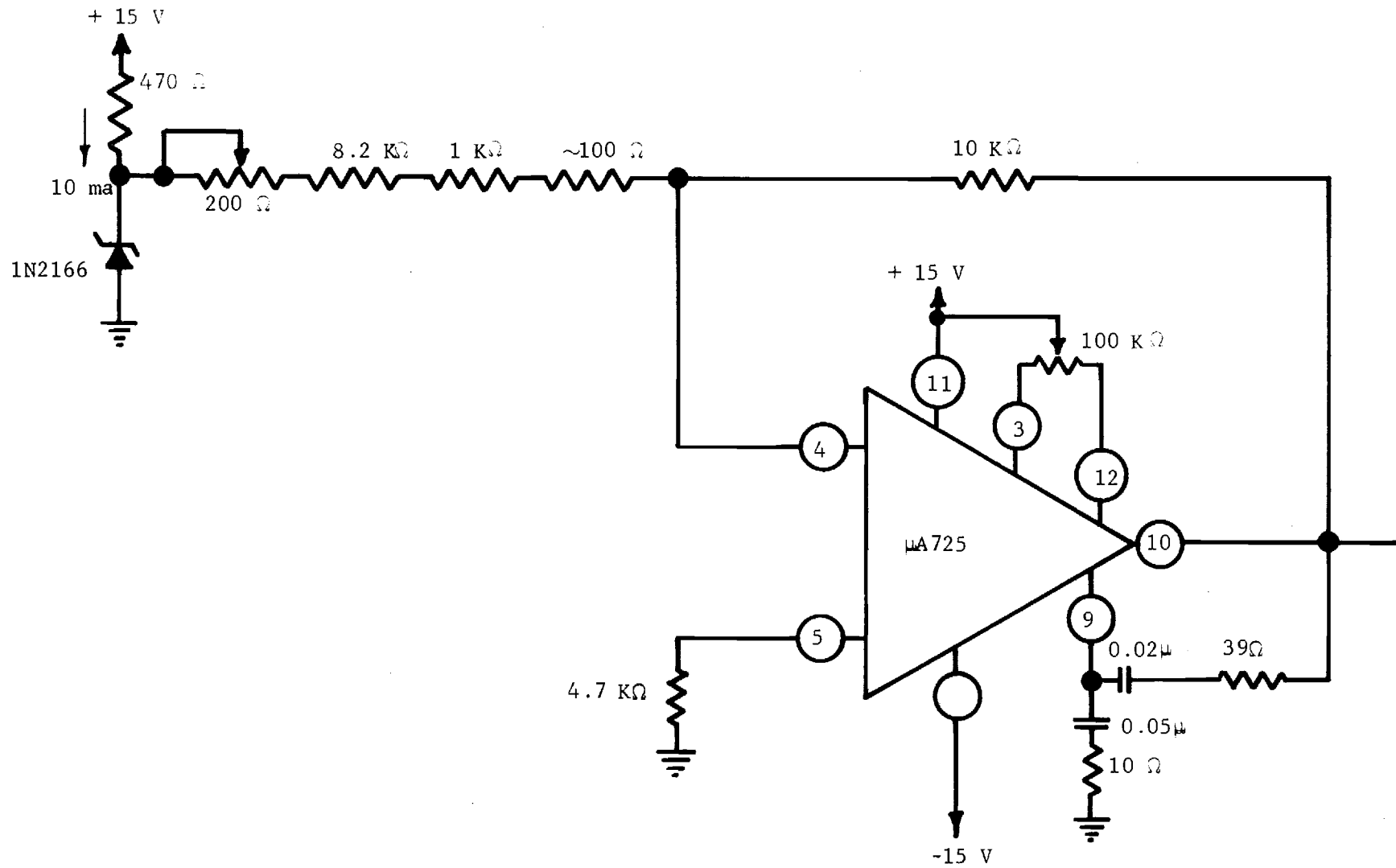


Figure 13. Schematic of Reference Voltage Supply.

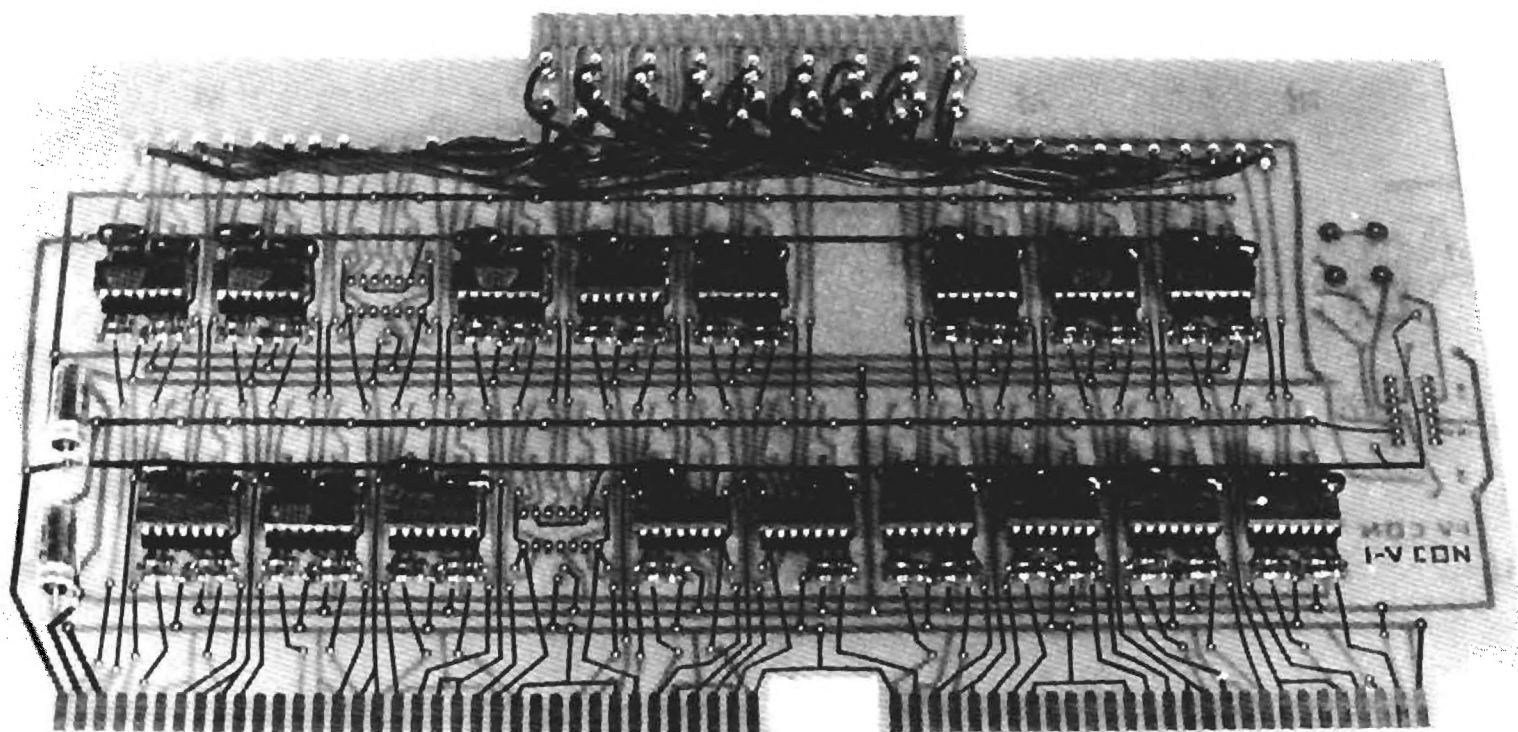
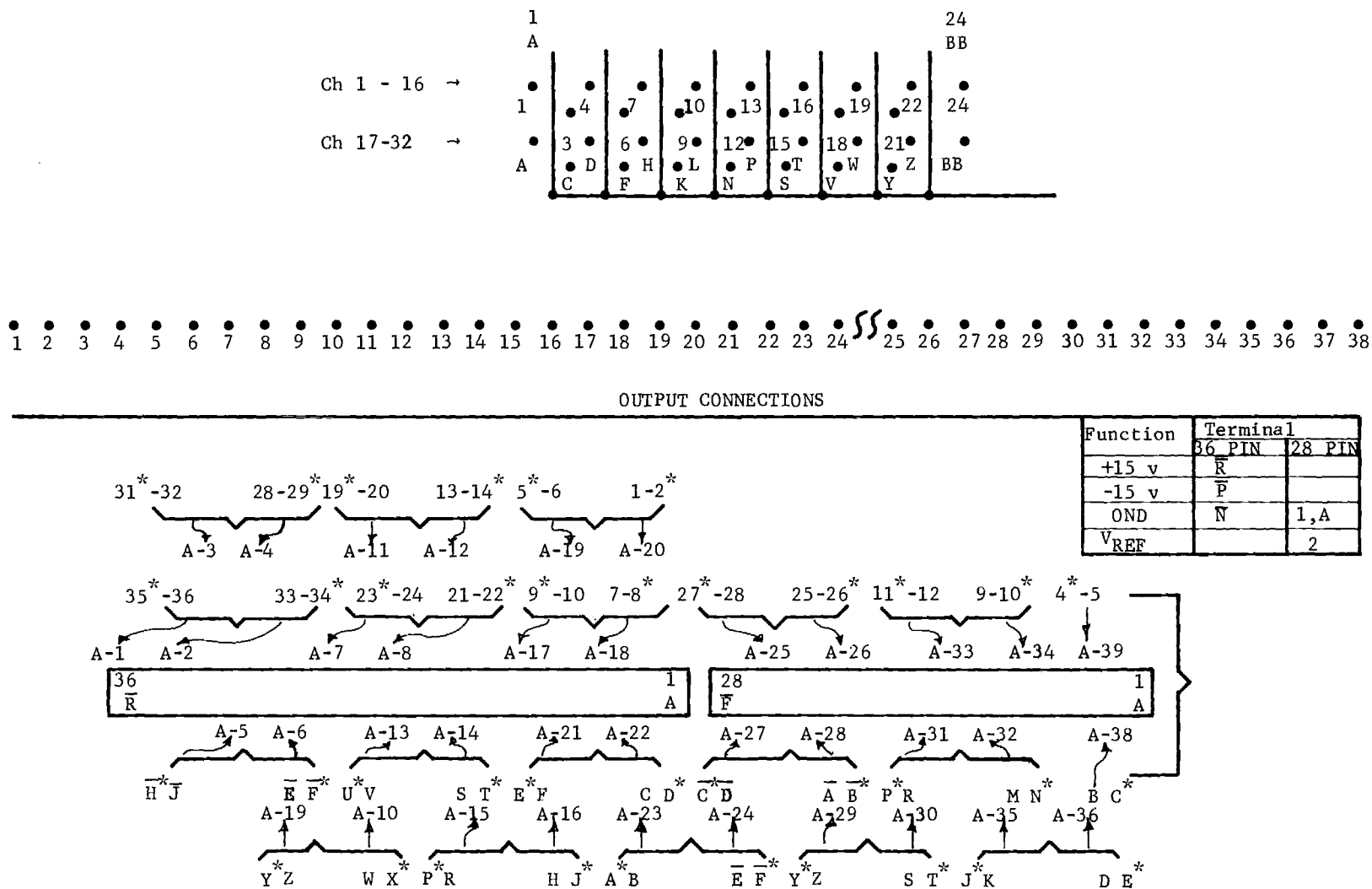


Figure 14. Photograph of a Typical Circuit Board (Circuit Board No. 2).

converters. Only those amplifier positions required to provide the necessary output for each of the six boards are connected on a specific board. There are positions for 38 individual amplifiers on each board, and the amplifiers are designated by a number from 1 to 38. The top row of amplifiers consists of nine integrated circuit packages containing 18 amplifiers. From left to right the amplifiers are designated by numbers A1-2, A5-6, A9-10, A13-14, A17-18, A21-22, A27-28, A31-32, and A35-36. Each of the integrated circuit packages contains two amplifiers. The bottom row, from left to right contains amplifiers A3-4, A7-8, A11-12, A15-16, A19-20, A23-24, A25-26, A29-30, A33-34 and A37-38. The outputs of each of the current-to-voltage converters which uses one of the amplifiers has its output connected to one of the pins in the row near the top edge of the circuit board running straight across the board. The amplifier output pins are numbered from 1 to 38 from left to right as shown in Figure 14. The printed circuit contacts at the top of the board are those which mate with the 38 contact connector which connects the current-to-voltage converters to the 2313B subsystem. Each of the 32 contacts at the top of the board, which are analog channel inputs, are terminated in pins just below the top printed circuit connector conductors. Jumpers are used to connect the appropriate amplifier output (from the row of 38 pins) to the appropriate pin for the output connector. Thirty-two amplifiers are connected on the first five boards. Only nine are connected on the sixth board.

Figure 15 shows the input and output connections to a circuit board. The input connections are shown for all possible diode input connections. Only a maximum of 32 input connections are used per board. The diode which collects light from the center fiber is connected to amplifier 29 on circuit board number one. This diode has its cathode connected to pin Y on the 56 pin connector and its anode connected to pin Z. Tables VI through XI indicate the input connector pin number to which the diodes anodes are connected, the amplifier used, and the output connector pin number to which the amplifier is jumpered for each of the six board. Figure 15 also gives the corresponding pins to which the diode cathodes are connected. For example, the center fiber, which is designated channel one, is connected to



*Denotes Common or Ground Connection

INPUT CONNECTORS

Figure 15. Circuit Board Input and Output Connections.

TABLE VI
CIRCUIT BOARD NO. 1 CONNECTIONS

2313B HLMPX Card 1 (Slot 3) <u>Channel No.</u>	Input Connector and Contact to Which Diode Anode <u>Is Connected</u>	<u>Amplifier</u>	Output Connector <u>Contact</u>
1	56-Z	A-29	1
2	56-S	A-30	3
3	56-K	A-35	4
4	56-D	A-36	6
5	72-J	A-5	7
6	72-E	A-6	9
7	72-V	A-13	10
8	72-S	A-14	12
9	72-F	A-21	13
10	72-C	A-22	15
11	56-D	A-26	16
12	56-A	A-28	18
13	56-R	A-31	19
14	56-M	A-32	21
15	56-B	A-38	22
16	72-36	A-1	24
17	72-33	A-2	A
18	72-24	A-7	C
19	72-71	A-8	D
20	72-10	A-17	F
21	72-7	A-18	H
22	56-28	A-25	K
23	56-25	A-26	L
24	56-12	A-33	N
25	56-9	A-34	P
26	56-5	A-37	S
27	72-32	A-3	T
28	72-28	A-4	V
29	72-20	A-11	W
30	72-13	A-12	Y
31	72-6	A-19	Z
32	72-1	A-20	BB

TABLE VII

CIRCUIT BOARD NO. 2 CONNECTIONS

2313 HLMPX Card 2 (Slot 4) <u>Channel No.</u>	Input Connector and Contact to Which Diode Anode <u>Is Connected</u>	<u>Amplifier</u>	Output Connector <u>Contact</u>
33	56- \overline{E}	A-24	1
34	56-Z	A-29	3
35	56-S	A-30	4
36	56-K	A-35	6
37	56-D	A-36	7
38	72- \overline{J}	A-5	9
39	72- \overline{E}	A-6	10
40	72-V	A-13	12
41	72-S	A-14	13
42	72-F	A-21	15
43	72-C	A-22	16
44	56- \overline{D}	A-27	18
45	56- \overline{A}	A-28	19
46	56-R	A-31	21
47	56-M	A-32	22
48	56-B	A-38	24
49	72-36	A-1	A
50	72-33	A-2	C
51	72-24	A-7	D
52	72-21	A-8	F
53	72-10	A-17	H
54	72-7	A-18	K
55	56-28	A-25	L
56	56-25	A-26	N
57	56-12	A-33	P
58	56-9	A-34	S
59	56-5	A-37	T
60	72-32	A-3	V
61	72-28	A-4	W
62	72-20	A-11	Y
63	72-13	A-12	Z
64	72-6	A-19	BB

TABLE VIII
CIRCUIT BOARD NO. 3 CONNECTIONS

HP2313 HLMPX Card 3 (Slot 5) <u>Channel No.</u>	<u>Input Connector and Contact to Which Diode Anode Is Connected</u>	<u>Amplifier</u>	<u>Output Connector Contact</u>
65	72-B	A-23	1
66	56-E	A-24	3
67	56-Z	A-29	4
68	56-S	A-30	6
69	56-K	A-35	7
70	56-D	A-36	9
71	72-J	A-5	10
72	72-E	A-6	12
73	72-V	A-13	13
74	72-S	A-14	15
75	72-F	A-21	16
76	72-C	A-22	18
77	56-D	A-27	19
78	56-A	A-28	21
79	56-R	A-31	22
80	56-M	A-32	24
81	56-B	A-38	A
82	72-36	A-1	C
83	72-33	A-2	D
84	72-29	A-7	F
85	72-21	A-8	H
86	72-10	A-17	K
87	72-7	A-18	L
88	56-28	A-25	N
89	56-25	A-26	P
90	56-12	A-33	S
91	56-9	A-34	T
92	56-5	A-37	V
93	72-32	A-3	W
94	72-28	A-4	Y
95	72-20	A-11	Z
96	72-13	A-12	BB

TABLE IX
CIRCUIT BOARD NO. 4 CONNECTIONS

2313 HLMPX Card 4 (Slot 6) <u>Channel No.</u>	<u>Input Connector and Contact to Which Diode Anode Is Connected</u>	<u>Amplifier</u>	<u>Output Connector Contact</u>
97	72-H	A-16	1
98	72-B	A-23	3
99	56- \overline{E}	A-24	4
100	56-Z	A-29	6
101	56-S	A-30	7
102	56-K	A-35	9
103	56-D	A-36	10
104	72- \overline{J}	A-5	12
105	72- \overline{E}	A-6	13
106	72-V	A-13	15
107	72-S	A-14	16
108	72-F	A-21	18
109	72-C	A-22	19
110	56- \overline{D}	A-27	21
111	56- \overline{A}	A-28	22
112	56-R	A-31	24
113	56-M	A-32	A
114	56-B	A-38	C
115	72-36	A-1	D
116	72-33	A-2	F
117	72-24	A-7	H
118	72-21	A-8	K
119	72-10	A-17	L
120	72-7	A-18	N
121	56-28	A-25	P
122	56-25	A-26	S
123	56-12	A-33	T
124	56-9	A-34	V
125	56-5	A-37	W
126	72-32	A-3	Y
127	72-28	A-4	Z
128	72-20	A-11	BB

TABLE X
CIRCUIT BOARD NO. 5 CONNECTIONS

2313B HLM PX Card 5 (Slot 7) <u>Channel No.</u>	<u>Input Connector and Contact to Which Diode Anode Is Connected</u>	<u>Amplifier</u>	<u>Output Connector Contact</u>
129	72-R	A-15	1
130	72-H	A-16	3
131	72-B	A-23	4
132	56- \overline{E}	A-24	6
133	56-Z	A-29	7
134	56-S	A-30	9
135	56-K	A-35	10
136	56-D	A-36	12
137	72- \overline{J}	A-5	13
138	72- \overline{E}	A-6	15
139	72-V	A-13	16
140	72-S	A-14	18
141	72-F	A-21	19
142	72-C	A-22	21
143	56- \overline{D}	A-27	22
144	56- \overline{A}	A-28	24
145	56-R	A-31	A
146	56-M	A-32	C
147	56-B	A-38	D
148	72-36	A-1	F
149	72-33	A-2	H
150	72-24	A-7	K
151	72-21	A-8	L
152	72-10	A-17	N
153	72-7	A-18	P
154	56-28	A-25	S
155	56-25	A-26	T
156	56-12	A-33	V
157	56-9	A-34	W
158	56-5	A-37	Y
159	72-32	A-3	Z
160	72-38	A-4	BB

TABLE XI

CIRCUIT BOARD NO. 6 CONNECTIONS

2313B HLMPX Card 6 (Slot 8)	Input Connector and Contact to Which Diode Anode Is Connected	<u>Amplifier</u>	Output Connector Contact
<u>Channel No.</u>			
161	72-W	A-10	1
162	72-R	A-15	3
163	72-H	A-16	4
164	72-B	A-23	6
165	56-E	A-24	7
166	56-Z	A-29	9
167	56-S	A-30	10
168	56-K	A-35	12
169	56-D	A-36	13

The remaining 23 input channels are unused.

pin Z on the 56 contact connector, and uses amplifier number 29, which is connected to output connector contact number one. The diodes are numbered from left to right looking down from the circuit board locations (see Figure 10). The bottom row contains diodes 1 through 4, the second row up contains diodes 5 through 15, etc. The first diode on the second board represents commutator channel number 33, is connected to pin E on the 56 pin connector, uses amplifier 24, and is jumpered to output connector pin 1 (see Table VII). The last diode used (channel 169) has its anode connected to pin D on the 56 pin connector, uses amplifier 36 whose output is jumpered to output connector pin 13 (see Table XI). Using the connection techniques allows one circuit board design to be used for each of the six circuit boards.

The circuit boards were laid out with the provision of mounting offset null potentiometers to zero the output voltage of the operational amplifiers. These were not mounted and the techniques for handling the variation in zero light level output voltage will be discussed in connection with the computer programs.

Power for the current-to-voltage converters is supplied from a Lambda Model LCD-4-22 power supply which furnishes ± 15 volts for the operational amplifiers and reference voltage supply. This power supply is mounted in a separate 19 inch rack panel and is connected to the current-to-voltage converters by means of the small Winchester connector on the box housing the converters.

B. Computer Program

The computer program used to operate the 2313B subsystem and to generate various forms of output data is described in this section. The output data may be hard copy generated on a teletype terminal or it may be a real time display of the spatial frequency data on an oscilloscope. The HP 2100 Series computer switch register is used to control the output modes. The program uses a main program written in FORTRAN and five subroutines--two in FORTRAN and three in Assembly language.

The main program, shown in Figure 16, controls the reading and display of the data. The first response of the program after it is started is the statement "Enter N". N is the number of sequential 2313B commutator channels which are to be sampled starting from the first channel which receives light from the center fiber. N can have any value from 1 to 169 which allows for reading of the data from the central fiber or the central fiber and the selected number of rings up to 168. Storage is not allocated for reading from more than 169 channels although 192 are available with the six high level multiplexer cards.

Reading and scaling of the data from the 2313B subsystem is performed by the FORTRAN subroutine RDAD shown in Figure 17. This subroutine calls the assembly language subroutine RD (Figure 18) to actually read the 2313B subsystem. Adding subroutine RD was a last minute change to accommodate the DOS-III system on the 2116B computer. The original RDAD subroutine used the HP BCS and the HP Fortran driver I2313 for the 2313B subsystem. The original RDAD subroutine is shown in Figure 19. Its operation will be described. The first call to the driver normalizes A/D conversion system, the second makes the readings, and the third checks the status to see if the readings have been completed. The data is read into the integer array IBF, the twelve bit data word occupying the 12 most significant bits of the computer word. This same function is performed in the DOS-III system by the subroutine RD. Conversion of the integer array to real numbers and scaling is also accomplished in this subroutine. The scaling accounts for the bit positions in the word converting the integer word values to floating point. The floating point data in the real array DATA has the range of zero to +20.475 volts. Channels for which data was not read contain the value zero.

The first call to the subroutine RDAD by the main program is for the purpose of reading zero light intensity values. These readings should be made with illumination removed from the input to the fiber optic bundles to compensate for ambient background light or any other light distribution which must be eliminated from the diffraction pattern. The readings vary from channel to channel partly because the balance pots to zero the

```

0001      FTN
0002      PROGRAM MAIN .
0003      DIMENSION ZIDTA(169)
0004      COMMON N,IBF(169),DATA(169),ALDTA(169)
0005      CALL EXEC(30,1)
0006      WRITE(1,200)
0007      READ(1,*) N
0008      CALL RDAD
0009      DO 5 I=1,169
0010      5 ZIDTA(I) = DATA(I)
0011      IF (IS(0)) 10,20,10
0012      10 WRITE(1,201)
0013      READ(1,*) NR1,NP1
0014      DO 15 I = NR1,NP1
0015      15 WRITE(1,211) I,DATA(I)
0016      20 CALL RDAD
0017      IF (IS(1)) 30,40,30
0018      30 WRITE(1,202)
0019      READ(1,*) NR1,NP1
0020      DO 35 I = NR1,NP1
0021      35 WRITE(1,211) I,DATA(I)
0022      40 DO 44 I = 1,N
0023      44 DATA(I) = DATA(I) - ZIDTA(I)
0024      IF (IS(2)) 50,60,50
0025      50 WRITE(1,203)
0026      READ(1,*) NR1,NP1
0027      DO 55 I = NR1,NP1
0028      55 WRITE(1,211) I,DATA(I)
0029      60 CALL LGDTA
0030      IF (IS(4)) 70,80,70
0031      70 WRITE(1,204)
0032      READ(1,*) NR1,NP1
0033      DO 75 I = NR1,NP1
0034      TEMP = (ALDTA(I)/128. - 255.) / 6.375
0035      75 WRITE(1,217) I,TEMP
0036      80 CALL WTDAL
0037      GO TO 20
0038      200 FORMAT("ENTER N")
0039      201 FORMAT("ENTER NSTART, NSTOP FOR ZERO INT DATA")
0040      202 FORMAT("ENTER NSTART, NSTOP FOR UNCOR DATA")
0041      203 FORMAT("ENTER NSTART, NSTOP FOR COR DATA")
0042      204 FORMAT("ENTER NSTART, NSTOP FOR LOG DATA")
0043      211 FORMAT(1X,13,1X,F9.4)
0044      217 FORMAT(1X,13,3X,F7.2)
0045      END
0046      END$
**** LIST END ****

```

Figure 16. Main Fortran Program.

```

0001      FTN
0002      SUBROUTINE RDAD
0003      COMMON N,IBF(169),DATA(169),ALDTA(169)
0004      CALL RD
0005      NN = N + 1
0006      DO 8 I = NN,169
0007      IBF(I) = 1000000B
0008      8 DATA(I) = 0.
0009      DO 7 I = 1,N
0010      7 DATA(I) = -(FLOAT(IAND(IBF(I),177760B)) * .0003125 - I
0011      RETURN
0012      END
0013      ENDS
**** LIST END ****

```

Figure 17. Subroutine RDAD for Reading and Scaling
Data from the HP 2313B Subsystem.

```

0001  ASMB,R,B,L,T
0002      NAM RD,7.
0003      ENT RD
0004      COM N,IBF(169)
0005  CLC   OCT 106725
0006      LDA CLC
0007      STA 25B
0008  RD    NOP
0009      LDA RD,I
0010      STA RTRN
0011      LDA N
0012      CMA,INA
0013      STA CTR
0014      LDA MPXR
0015      STA CODE
0016      LDA ILOC
0017      STA LOC
0018      LDB CTR
0019      CLC 25B
0020  LOOP  LDA CODE
0021      OTA 25B
0022      STC 25B,C
0023      SFS 25B
0024      JMP *-1
0025      LIA 25B
0026      SFS 25B
0027      JMP *-1
0028      STA LOC,I
0029      ISZ CODE
0030      ISZ LOC
0031      INB,SZB
0032      JMP LOOP
0033      JMP RTRN,I
0034  RTRN  BSS 1
0035  CTR   BSS 1
0036  MPXR  OCT 100140
0037  CODE  BSS 1
0038  ILOC  DEF IBF
0039  LOC   BSS 1
0040      END
**** LIST END ****

```

Figure 18. Subroutine RD.

```

SUBROUTINE RDAD
COMMON N,IBF(169),DATA(169),ALDTA(169)
CALL I2313(7,0)
CALL I2313(7,2,0,2,000140B,N,IBF,0)
5 CALL I2313(7,1,ISTAT,ITLOG)
  IF(ISTAT) 5,6
6 CONTINUE
  NN = N + 1
  DO 8 I = NN,169
    IBF(I) = 1000000B
8 DATA(I) = 0.
  DO 7 I = 1,N
7 DATA(I) = -(FLOAT(IAND(IBF(I),177760B)) * .0003125 - 10.235)
  RETURN
END
END$

```

Figure 19. Original RDAD Subroutine.

operational amplifier output were not included on the circuit boards.

If it is desirable to print these zero intensity values switch register bit zero should be set equal to one. This bit is effective only when the program is stated, other active switch register bits may be activated at any time. If switch register bit zero is set to one, the program responds with "Enter N start, N stop for Zero Int Data". This allows any portion of the zero intensity readings to be printed on the teletype. If switch register bit zero is zero when the program is stated, the program proceeds to act on the status of switch register bits one through four.

The function of the switch register bits one through four control the printing of data in various forms and the oscilloscope display of data. Bit one on allows for the printing of uncorrected data, that is, data from which the zero intensity values have not been subtracted. Bit two on provides for the printing of corrected data. Corrected data is that data for which the zero light intensity values have been subtracted from the actual readings. Bit three on provides for real time display of the logarithm of the corrected data on an oscilloscope display. The display is operated in a refreshed mode so that changes in the measured data may be observed as changed in the spatial data are made. Switching bit three off causes a continuous display of the data that was in storage when bit three was switched off or when the program entered the WTDAL subroutine.

Switch register bit four controls the printing of the logarithm of the input data. Bit four on generates a request for the number of the channel where print of the data is to begin and where it is to stop.

Use of the switch register as described is accomplished through the assembly language coded function IS shown in Figure 20. It interrogates the status of the switch register (S-register) bit n in the 2100 series computer and returns a zero if the bit is off and to a non-zero value otherwise. The function is used to switch to two different sets of instructions depending on the status of bit n in the switch register. Switching is accomplished by arithmetic IF statements in the main program. Since the switch register is active during the time that the computer is running, use of the function IS provides a means of implementing optional features that can be accessed during the course of a run.


```

0001  ASMB,R,B,L,T
0002      NAM IS,7
0003      ENT IS
0004      EXT .ENTR
0005  CLC   106701
0006  AGMT  BSS 1
0007  IS    NOP
0008      JSB .ENTR
0009      DEF AGMT
0010      LDA CLC
0011      STA 1B
0012      LDA AGMT,I
0013      SSA
0014      JMP IS,I
0015      CMA
0016      CLB,CCE
0017      ELB,CLE
0018      INA,SZA
0019      JMP *-2
0020      LIA 1
0021      AND 1
0022      JMP IS,I
0023      END
**** LIST END ****

```

Figure 20. Assembly Language Routine IS.

Output of the data to the oscilloscope for display purposes is provided with the amplitude having logarithmic values. This allows observation of light levels over a dynamic range greater than three orders of magnitude. The logarithm of the data is computed in the FORTRAN subroutine LGDA shown in Figure 21. The data in array DATA is placed in array ALDTA in normalized form. The data is tested for zero or negative values before the logarithm is taken, and for any data having these values the value of -40 dB is inserted in its place in the array ALDTA. The logarithm of valid data is inserted in its proper place in the array ALDTA.

The last operation in the subroutine LGDTA is the scaling of the data for an 8 bit D/A converter (HP-12555B).

The assembly language subroutine WTDAL (Figure 22) is used to write the logarithm of the measured values on an oscilloscope. This subroutine places a dot on the oscilloscope display at 10 dB intervals in the vertical direction along the same vertical line where channel one data is displayed. The horizontal axis is marked with dots every ten channels for 200 channels at the -40 dB level.

C. Subsystem Characteristics

When the system is initially set up, the reference voltage from the reference voltage supply on circuit board number one must be set so that all of the zero light intensity output voltages of the current-to-voltage converters are within the input voltage range of the HP2313 analog to digital converter. To do this the computer program may be used to print the zero light intensity values. The input plane of the fiber optics bundles should be blocked to prevent ambient light from producing erroneous readings. The zero intensity values may be printed by setting switch register bit zero on before the program is started. All 169 channels should be printed. The voltage reading should be in the range of approximately one volt or less. If any channels read zero, this is an indication that the reference voltage is not set correctly. In tests conducted on the equipment, it was found that the reference voltage needed to be set to 9.736 volts to bring all channels on scale. The reference voltage may be measured at pin number 2 on the 56 pin connector with a digital

```

0001      FTN
0002      SUBROUTINE LGDTA
0003      COMMON N,IBF(169),DATA(169),ALDTA(169)
0004      DO 1 I = 1,169
0005      IF(DATA(I)) 2,2,3
0006      3 ALDTA(I) = DATA(I) / 20.475
0007      ALDTA(I) = 4.343 * ALOG(ALDTA(I))
0008      GO TO 1
0009      2 ALDTA(I) = -40.
0010      1 CONTINUE
0011      DO 20 I = 1,169
0012      20 ALDTA(I) = (255. + 6.375 * ALDTA(I)) * 128.
0013      RETURN
0014      END
0015      ENDS
**** LIST END ****

```

Figure 21. Fortran Subroutine LGDTA.

```

0001  ASMB,R,B,L,T
0002      NAM WTDAL,7
0003      ENT WTDAL
0004  IBLC  DEF ALDTA
0005      COM N,IBF(169),DATA(338),ALDTA(338)
0006  CLC   OCT 106716
0007  WTDAL NOP
0008      LDA CLC
0009      STA 16B
0010      LDA WTDAL,I
0011      STA RETRN
0012  START LDB ISTRT
0013      STB INDEX
0014      LDB XST
0015      STB X
0016      LDB IBLC
0017      STB ALDST
0018      SFS SCOPE
0019      JMP *-1
0020      CLF SCOPE
0021      LDA SCAST
0022      STA POS
0023      LDA XCTRS
0024      STA CTR
0025  XSCA  LDA POS
0026      OTA SCOPE
0027      ADA TEN
0028      STA POS
0029      ISZ CTR
0030      JMP XSCA
0031      LDA SCAST
0032      STA POS
0033      LDA YCTRS
0034      STA CTR
0035  YSCA  LDA POS
0036      OTA SCOPE
0037      ADA SIXF
0038      STA POS
0039      ISZ CTR
0040      JMP YSCA
0041      LDA ZDB
0042      OTA SCOPE

```

Figure 22. Subroutine WTDAL for Writing the Logarithm of the Observed Light Values on an Oscilloscope.

```

0043  LOOP  DLD ALDST,I
0044      FIX
0045      RAL
0046      AND MASK
0047      ADA X
0048      OTA SCOPE
0049      ISZ X
0050      ISZ ALDST
0051      ISZ ALDST
0052      ISZ INDEX
0053      JMP LOOP
0054      LIA I
0055      AND IBIT3
0056      SZA
0057      JMP RETRN,I
0058      JMP START
0059  XST  OCT 1
0060  MASK OCT 177400
0061  ISTRT DEC -169
0062  RETRN BSS 1
0063  INDEX BSS 2
0064  SCOPE EQU 16B
0065  X      EQU INDEX+1
0066  SCAST DEC 0
0067  POS   BSS 1
0068  XCTRS DEC -21
0069  CTR   BSS 1
0070  YCTRS DEC -4
0071  YSCAR OCT 200
0072  ALDST BSS 1
0073  ZDB   OCT 177400
0074  TEN   DEC 10
0075  SIXF  OCT 40000
0076  IBIT3 OCT 10
0077      END
**** LIST END ****

```

Figure 22. (Concluded)

voltimeter. It is adjusted with the potentiometer located on the right hand side of printed circuit board number one nearest the center of the board. Once all the voltage readings are brought on scale, any light incident on the photodiodes will provide an in range input voltage to the analog to digital converter. A typical print out of the first thirty two zero light intensity voltages is shown in Figure 23.

Using some of the Hewlett-Packard furnished diagnostic software, histograms of the voltage reading on selected channels may be made. Figure 24 shows a histogram for the first ten channels. The histograms were obtained for 30,000 consecutive readings on each channel. A quiet channel is indicated by a small number of different voltage levels encountered during the time that the measurements were being taken. The entries for BX, CD, CH indicate the box number in the HP2313B subsystem for which the readings were taken (zero since this is the first 2313B box used), the printed circuit card in box zero (which is three for the first high level multiplexer card), and the channel number on the specified card. The channel numbers on a card are numbered from 0 to 31. Thus, Figure 24 shows the histograms for the first ten of the 169 used channels. Most of the channels show fairly quiet operation particularly channels numbered 3 and 8 for which all of the 30,000 readings occurred at a single value of voltage. Channel number one was the noisiest with six analog-to-digital converter steps excited during the 30,000 readings. While most of the readings occurred at 10.195 volts, a small number of values were scattered over adjacent converter steps.

```

ENTER N
169
ENTER NSTART, NSTOP FOR ZERO INT DATA
1,169
  1      .7650
  2      .3150
  3      .4400
  4      .2250
  5      .5650
  6      .5450
  7      .5500
  8      .5000
  9      .1650
 10      .5900
 11      .1700
 12      .4900
 13      .6750
 14      .7250
 15      .6600
 16      .1500
 17      .3250
 18      .9600
 19      .2300
 20      .5250
 21      .5300
 22      .5100
 23      .3000
 24      .2600
 25      .3800
 26      .4300
 27      .4100
 28      .2100
 29      .3300
 30      .9400
 31      .6250
 32      .4400

```

Figure 23. Zero Light Intensity Voltages for Channels 1-33.

```

>HI
NO= 3000
BX,CD,CH = 0 3 0
AVC= 9.731192 PP= .005001 HI= 9.735001 LO= 9.730000 RMS= .00213078
9.730000 22850
9.735001 7150

>HI
NO= 3000
BX,CD,CH = 0 3 1
AVC= 10.195089 PP= .025000 HI= 10.209999 LO= 10.184999 RMS= .00083666
10.184999 4
10.190000 100
10.195000 29287
10.199999 569
10.205000 39
10.209999 1

>HI
NO= 30000
BX,CD,CH = 0 3 2
AVC= 10.054985 PP= .010000 HI= 10.059999 LO= 10.049999 RMS= .00027952
10.049999 93
10.055000 29906
10.059999 1

>HI
NO= 30000
BX,CD,CH = 0 3 3
AVC= 10.235001 PP= .000000 HI= 10.235001 LO= 10.235001 RMS= .00000000
10.235001 30000

>HI
NO= 30000
BX,CD,CH = 0 3 4
AVC= 9.933872 PP= .004999 HI= 9.934999 LO= 9.930000 RMS= .00208931
9.930000 6766
9.934999 23234

>HI
NO= 30000
BX,CD,CH = 0 3 5
AVC= 9.950611 PP= .010000 HI= 9.955000 LO= 9.945000 RMS= .00163883
9.945000 1
9.949999 26330
9.950000 3669

>HI
NO= 30000
BX,CD,CH = 0 3 6
AVC= 9.947968 PP= .004999 HI= 9.949999 LO= 9.945000 RMS= .00245549
9.945000 12195
9.949999 17805

>HI
NO= 30000
BX,CD,CH = 0 3 7
AVC= 10.004999 PP= .005001 HI= 10.010000 LO= 10.004999 RMS= .00004083
10.004999 29998
10.010000 2

>HI
NO= 30000
BX,CD,CH = 0 3 8
AVC= 10.235001 PP= .000000 HI= 10.235001 LO= 10.235001 RMS= .00000000
10.235001 30000

>HI
NO= 30000
BX,CD,CH = 0 3 9
AVC= 9.909349 PP= .004999 HI= 9.910000 LO= 9.905001 RMS= .00168362
9.905001 3913
9.910000 25087

```

Figure 24. Histograms of Voltage Readings on Selected Channels.

V. SYSTEM PERFORMANCE

The final measure of performance for a coherent optical processor for the subject application should be described in terms of the degree of success for which the desired pattern recognition operations can be performed. The goal of this program has been the development of an automatic diffraction pattern sampling system for classification of forested land areas from aerial photographs. The complexity of the system concept and the limited resources available have resulted in the major program emphasis being directed toward hardware development. In view of the hardware emphasis necessitated by the scope of this program, very little effort was expended in developing digital processing algorithms for classification of forestry images. Consequently, the preliminary performance criteria have been based on diffraction pattern sampling effectiveness.

The performance of the diffraction pattern sampling system consisting of the fiber optic detector and its associated electronic interface subsystem can be discussed in terms of its radial distribution function for uniform illumination, radiometric sensitivity, dynamic range for linear response, and adjacent ring cross coupling. As discussed in Section II, the concentric ring fiber optic detector divides the Fourier transform plane into zones of constant spatial frequency with finite bandwidth. The spatial frequency, ν_s , is given by

$$\nu_s = \frac{dn}{\lambda f}, \quad (3)$$

where d is the diameter of the optical fiber,

n is the ring number,

λ is the wavelength of the coherent optical source, and

f is the focal length of the Fourier transform lens.

The spatial frequency bandwidth, $\Delta\nu_s$, is constant for each zone, and is given by

$$\Delta\nu_s = \frac{d}{\lambda f} \quad (4)$$

The spatial frequency can be thought of as a scale factor relating periodic changes of object transparency to periodic changes in the intensity of the Fourier transform diffraction pattern. Since the object function can be approximated by a finite sum of properly weighted periodic grating functions, the analysis of the Fourier transform of any object can be approached in a systematic manner. It is, therefore, important to know how the diffraction plane detector weights the diffraction pattern as a function of spatial frequency.

The linearity of the photodetector-operational amplifier pairs was investigated by illuminating the photodetector with sufficient irradiance to produce the maximum 20 volt input of the HP 2313B subsystem, which was described in Section IV, and recording the voltage output as a function of decreasing irradiance. A typical linearity curve measured for a UDT - 5DP photodetector - μ A 747 operational amplifier pair is shown in Figure 25. The linearity is shown to exceed the 36 dB dynamic range of the A/D converter.

The radial distribution function and the calculation of system sensitivity was based on the recording of the light background corrected output voltages of the 169 channels for illumination of the detector face by a uniform light source. It was found that this recording contained discontinuities in the distribution of points at the ring locations corresponding to changes in the photodiode types. An analysis of the photodiode - fiber optic bundle mounting geometry revealed that radiation losses were occurring because the active element of the photodiode, which is recessed about 0.3 cm below the window of the photodiode housing, subtends a much smaller solid angle than the radiation solid angle of the fiber optic bundle. Calculations were made to determine the losses incurred for each range of fiber bundles assigned to the three diode types. These calculations along with a diagram of the fiber bundle - photodiode mounting geometry is shown in Figure 26. When these loss components are included in the radial distribution characteristic of equation (1), the discontinuous behavior is accounted for.

The measured and calculated distribution characteristics for the complete diffraction pattern sampling system are shown in Figure 27. The

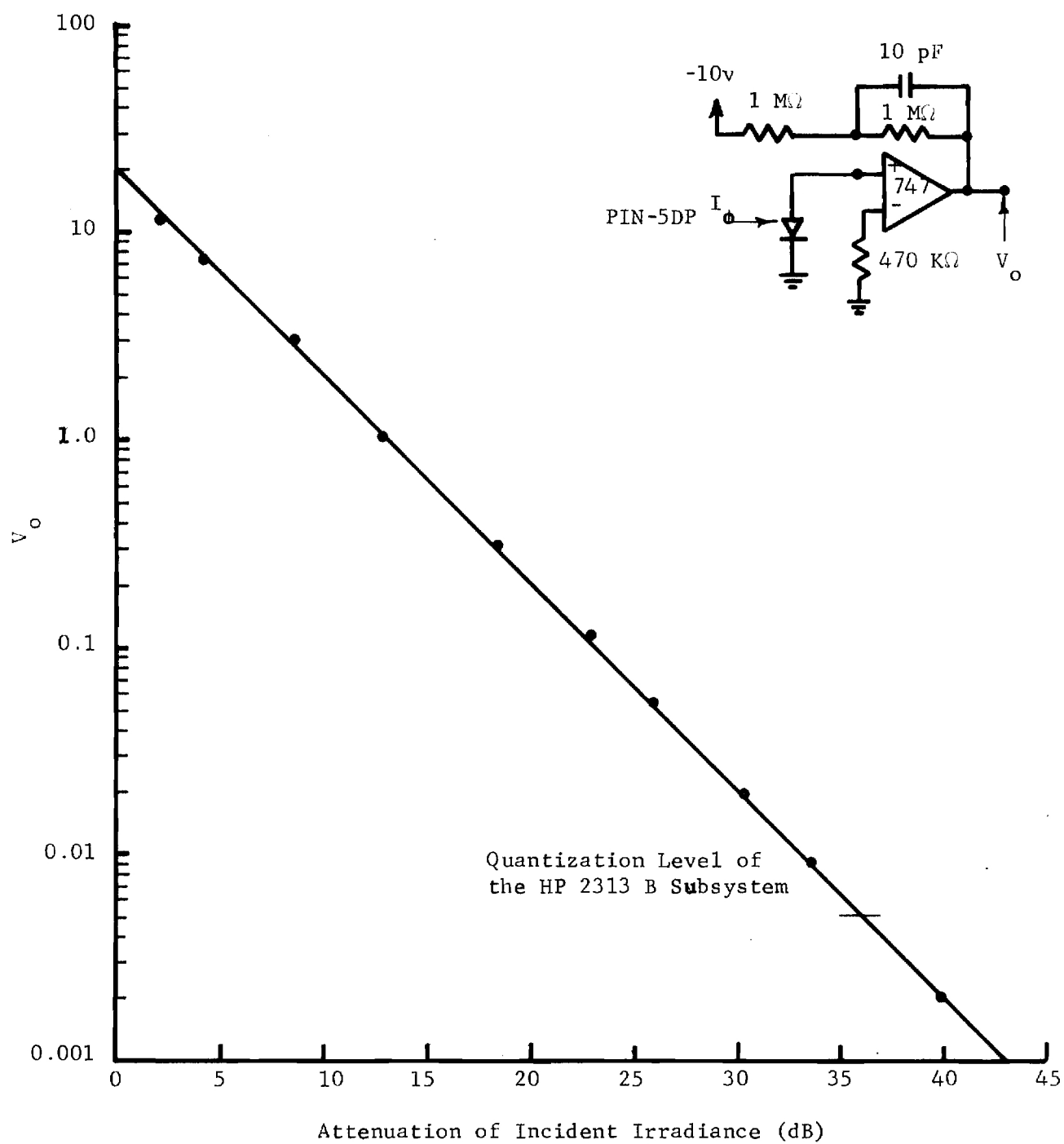
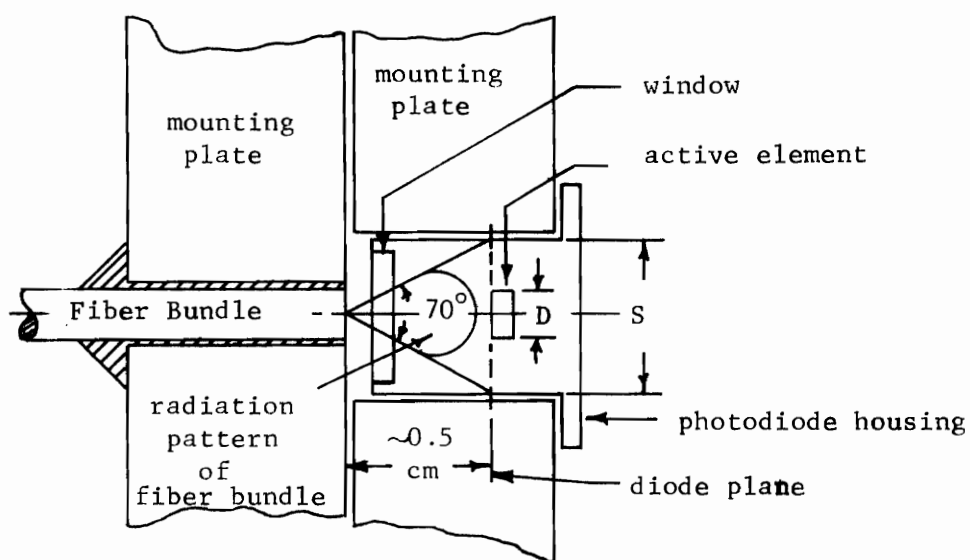


Figure 25. Linearity of the Photodetector-Operational Amplifier Pair.



$$S \approx d_B + 2L \tan \theta/2 = d_B + 0.7$$

Photodiode	Diameter of Active Element, D(cm)	Ring Number Assignments	Loss $(10 \log D/S)^2$
3 DP	0.20	1 - 31	5.4 → 6.1 dB
5 DP	0.26	32 - 121	4.9 → 5.4 dB
6 DP	0.51	122 - 169	2.5 → 2.7 dB

Figure 26. Geometry of Fiber Bundle - Photodiode Termination and Radiation Loss Calculations.

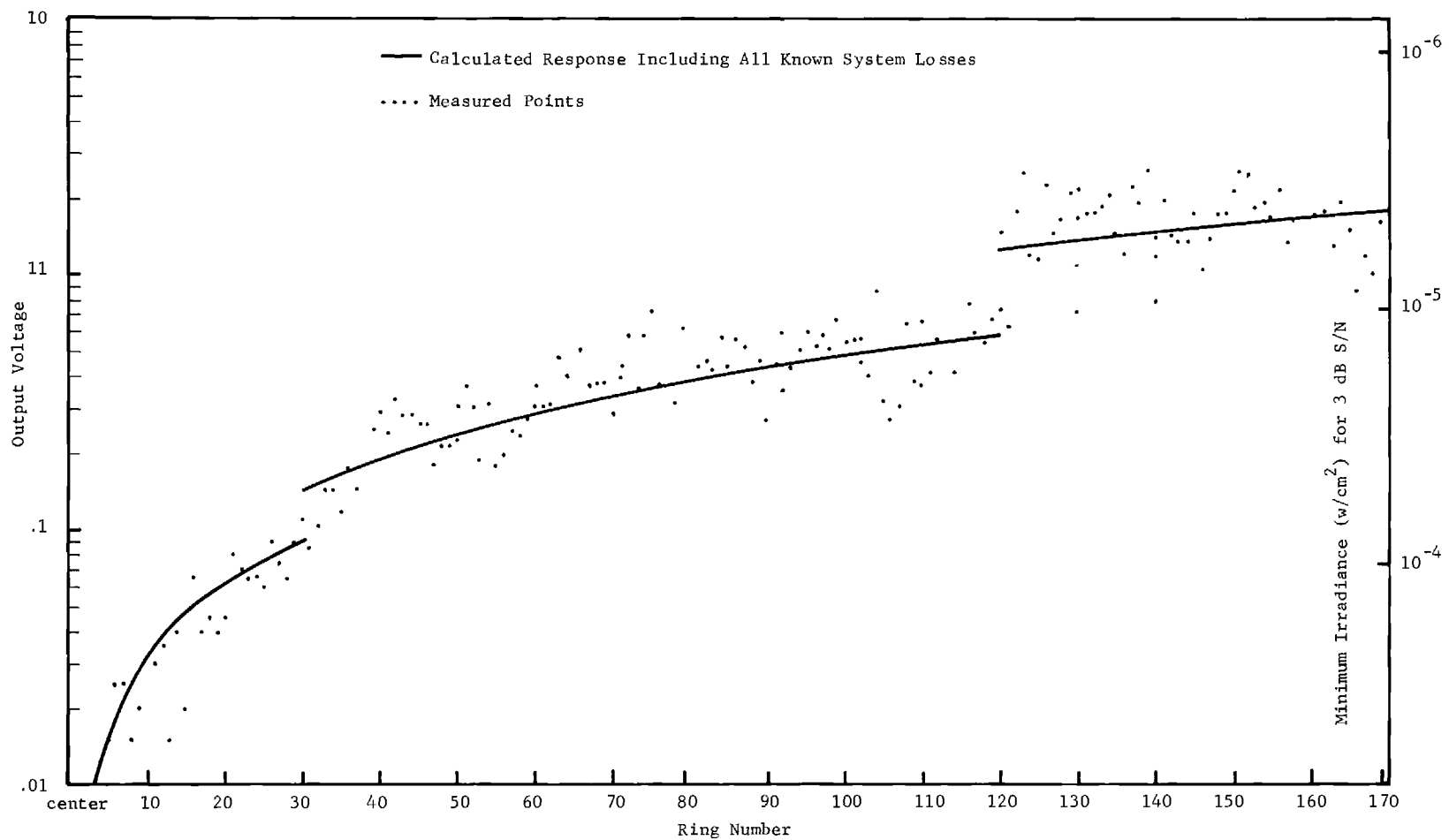


Figure 27. Radial Distribution Function of the Diffraction Pattern Sampling System.

measured points for the system characteristic are more widely distributed about the calculated characteristic than those for the fiber optic radial distribution shown in Figure 8. The wider distribution of points is a result of the spread in off-the-shelf photodiode sensitivities. A statistical analysis of the responses of the photodiodes incorporated into the system to an input irradiance of $190 \mu\text{W}/\text{cm}^2$ is given below:

<u>Photodiode Type</u>	<u>Mean Output Voltage (\bar{v}_o)</u>	<u>% Standard Deviation ($\sigma/\bar{v}_o \times 100$)</u>	<u>% Maximum Deviation</u>
3 DP	1.6371	17.3	+37.4 - 41.4
5 DP	2.7173	10.2	+31.7 - 17.6
6 DP	9.0688	21.2	+74.2 - 29.4

Although the statistics of the operational amplifiers were not determined, a smaller spread in gain characteristics would be expected. No provisions were made to compensate for these variations in the electronics since dynamic changes can be expected to occur, and since these variations can be easily removed in the digital processing operations.

The sensitivity was determined by measuring the output signal-to-noise ratio for each channel under conditions of uniform illumination. These measurements are expressed in terms of the minimum irradiance as a function of radial coordinate for a 3 dB S/N at the HP 2313B output, and the minimum power incident on each photodiode for 3 dB S/N at the HP 2313B output. The minimum irradiance is given on the right hand ordinate of Figure 27, and the minimum power levels for the photodiodes are given below:

<u>Photodiode Type</u>	<u>$P_{\min}(w)$ for 3 dB S/N at the Output of the HP 2313B Subsystem</u>
3 DP	9.73×10^{-8}
5 DP	5.74×10^{-8}
6 DP	2.60×10^{-8}

Although it is difficult to relate these sensitivity measurements to potential performance goals, certain criteria for the subject application can be suggested. The diffraction pattern of a low contrast image will be determined by its aperture function. If we assume that a 1 mm laser beam is used to scan aerial photograph (1 mm corresponds to ~ 1 acre on the 70 mm imagery), the principle maximum of the diffraction pattern is contained within the first five rings for the present optical system parameters. The relative intensity of the remaining distribution, which contains the spatial information, is proportional to $m^2/4$, where m is the modulation index. For $m = 0.5$, the average irradiance of the information carrying spatial distribution is approximately 10^{-4} w/cm² for object irradiance of 3.8 w/cm². Assuming a 3 dB S/N, the required sensitivity is about 2×10^{-5} w/cm². From this simple approximation, and the data of Figure 27 it is evident that the present system sensitivity is not adequate for low resolution spatial analysis. This conclusion was, unfortunately, found to be accurate when forestry diffraction patterns were recorded from the 70 mm aerial film.

The radiometric sensitivity of the fiber optic detector is affected by the cross coupling between adjacent rings. This is an especially important consideration near the center of the array where the undiffracted light intensity is much greater than that near the edges. To measure the magnitude of cross coupling, the spatial filtered and expanded laser beam (2 inch diameter) was projected through the Fourier transform lens and focused on the center fiber of the array. Precise centering of the focused spot was accomplished by observing the diffraction pattern in real time on the oscilloscope display of the digital processing system. This centered distribution was then printed out on the teletype, and the cross coupling was determined from the light background corrected voltage readings. With careful alignment, it was found that the voltage on the first ring was 29.7 dB below the center fiber voltage, and that the voltage of all higher number rings was at the lowest quantization level of the HP 2313B A/D converter. Calculation of the diffraction pattern of a circular aperture of 2 inch diameter showed that the envelope of the intensity distribution for diffraction limited conditions would be about 45 dB

below the principal maximum at the radius corresponding to the first ring of the array. Thus it appears that the adjacent ring cross coupling level is about -30 dB, and that the dynamic range of the first ring would be reduced by only 6 dB. Since very little information will be contained in the low spatial frequency region, this performance level is satisfactory.

A potential system requirement that surfaced unexpectedly during the radiometric sensitivity tests should be mentioned because of its potential importance to pattern recognition processing. The argon laser used in these tests employs an internal light regulator, and according to manufacturer's specifications, the noise in a 10 Hz to 2 MHz bandwidth is $< 0.7\%$, and the long term amplitude stability is $< 1\%$ (1 sec. to 10 hours). During extended tests, the short term stability of the expanded and spatially filtered laser beam was observed to be about 10%. The stability for various intensity levels was measured, and found to be about the same. Interestingly, the stability of the unexpanded and unfiltered laser beam was measured, and found to be well within the specifications, with long term stability over several minutes below 0.5%. The degradation in stability was traced to two primary phenomena. The most serious problem was the poor vibrational isolation of the long optical path coupled with the positional sensitivity of the pinhole spatial filter. The presence of dust particles in the beam ahead of the spatial filter was also found to contribute to amplitude noise.

The stability was greatly improved by remounting the spatial filter, beam collimeter, and beam directing mirrors on short-stemmed, massive mounts, and enclosing the beam paths with plastic tubes to reduce the dust circulation. In addition, an external light amplitude feedback system was added to the laser by sampling part of the expanded and spatially filtered beam, and injecting a voltage proportional to the sampled intensity into the light regulator control loop. Without any attempt at optimization of this control loop, the short term stability and amplitude noise level was reduced to about 0.1%.

During processing operations, it will be necessary to impose amplitude stability requirements on the coherent source during the sampling interval

required for scanning the 169 photodiode outputs. The noise level of the laser beam will have to be at least 36 dB below the average intensity to utilize the full dynamic range of the A/D converters in the present processing scheme. Thus, the required noise and short term stability would be about 0.025%. Several alternatives to this requirement will be discussed in Section VI.

Operation of the digital processing system for analysis of the sampled diffraction patterns was described in Section IV, and the reader is referred there for details pertaining to operating procedures for the tests described in the following text. A photograph of the diffraction pattern sampling system is shown in Figure 28.

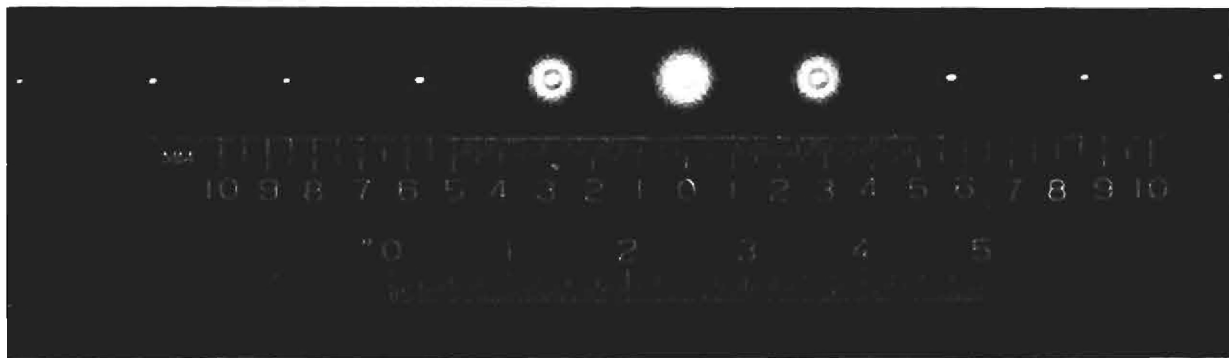
The accuracy of scaling between the object plane and the diffraction plane was confirmed by recording the diffraction pattern of a 250 line/inch ruled grating. A photograph of the diffraction pattern obtained by placing a film plate in the Fourier transform plane, and a photograph of the oscilloscope display of the optical processor is shown in Figure 29. The calculated and measured diffraction maxima of the 250 line/inch grating were found to be:

Diffraction Order	CALCULATED MAXIMA		MEASURED MAXIMA
	Radius (mm)	Ring Number ($R(\text{mm})/0.076+1$)	Ring Number (from teletype print-out)
0	0	1	1
1	2.88	38.8	39
2	5.76	76.6	76
3	8.63	114.3	115
4	11.51	152.1	152

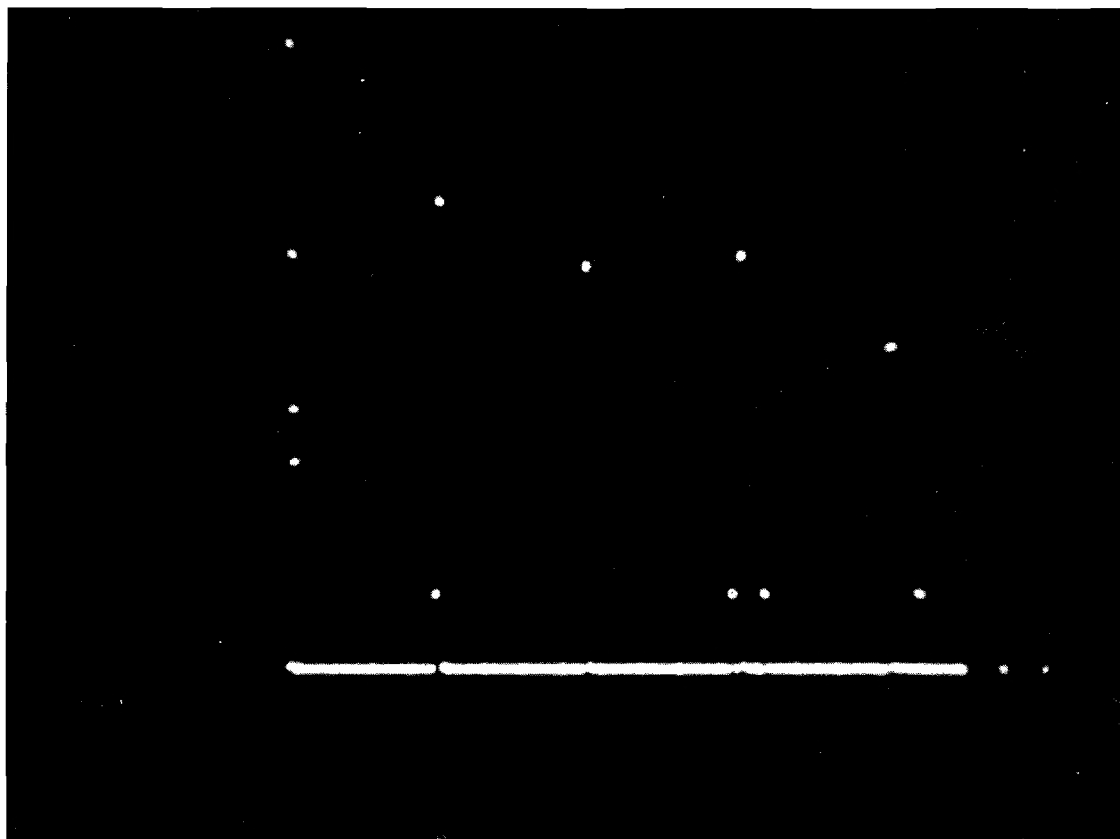
Using the optical system parameters ($f = 23.58$ in, $\lambda = 1.921 \times 10^{-5}$ in.) and the measured spacing between the diffraction maxima as determined from the teletype print-out, the grating frequency was calculated to be 250.15 lines/inch. These measurements demonstrate the excellent accuracy with which object frequencies can be determined from the sampled diffraction patterns.



Figure 28. A Photograph of the Automatic Diffraction Pattern Sampling System.



(a) Photograph of the Diffraction Pattern.



(b) Photograph of the Oscilloscope Display.

Figure 29. Diffraction Pattern and Automatic Diffraction Pattern Sampling System Display for a 250 Line/Inch. Grating Object.

A practical example of this type of analysis can be shown from Figure 30 which is a 20 power enlargement of a frame of the 70 mm aerial imagery taken over Huntsville, Alabama. This photograph represents an area of approximately 2.6 x 3.2 miles located on the Redstone Arsenal, which includes a parallel array of roads and buildings located at about the middle of the frame. This grating like structure occupied an area of about 3.5 x 1.2 mm on the 70 mm film, and could be easily resolved with the unaided eye. Figure 31 shows a photograph of the Fourier transform diffraction pattern of the parallel structure of Figure 30 and its radial distribution function measured by the diffraction pattern sampling system. Three equally spaced diffraction maxima can be clearly seen above the background noise on the oscilloscope photograph of Figure 31. The grating spacing of the parallel structure was determined under a microscope, and the calculated and measured maxima are given below.

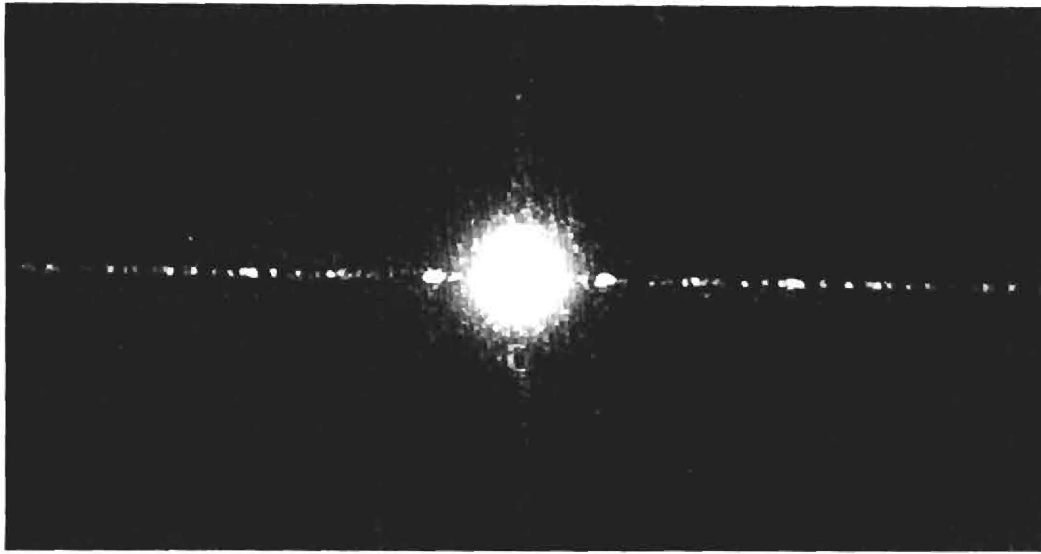
Diffraction Order	CALCULATED MAXIMA		MEASURED MAXIMA	
	Radius (mm)	Ring Number ($R(\text{mm})/0.76+1$)	Ring Number (from teletype print-out)	
0	0	1	1	
1	1.21	15.9	16	
2	2.42	31.8	33	
3	3.63	47.7	49	
4	4.85	63.6	-	

The calculated and measured results are in excellent agreement in view of the relatively low accuracy of the microscopic measurements which were performed with the aid of an optical comparator.

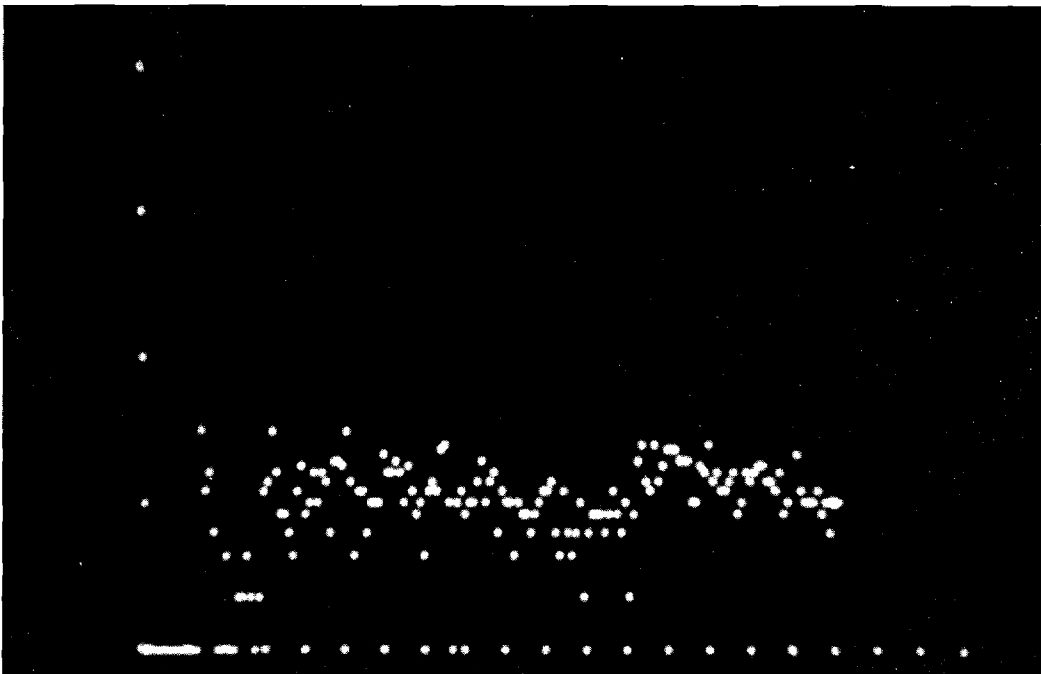
As a final example of simple pattern recognition which is possible with grating like objects, consider Figure 32 which shows an enlargement from an aerial photograph of row crops, and the diffraction pattern of one of the cultivated areas. In this case, the rows could not be resolved on the original aerial photograph without enlargement, although the regular



Figure 30. Aerial Photograph of a Section of Redstone Arsenal.



(a) Photograph of the Diffraction Pattern.



(b) Photograph of the Oscilloscope Display.

Figure 31. Diffraction Pattern and Automatic Diffraction Pattern Sampling System Display of a Parallel Line Structure on an Aerial Photograph of a Section of Redstone Arsenal, Alabama.

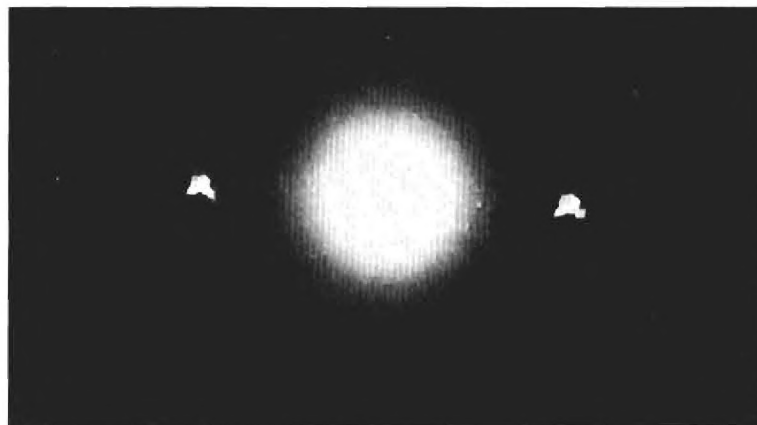
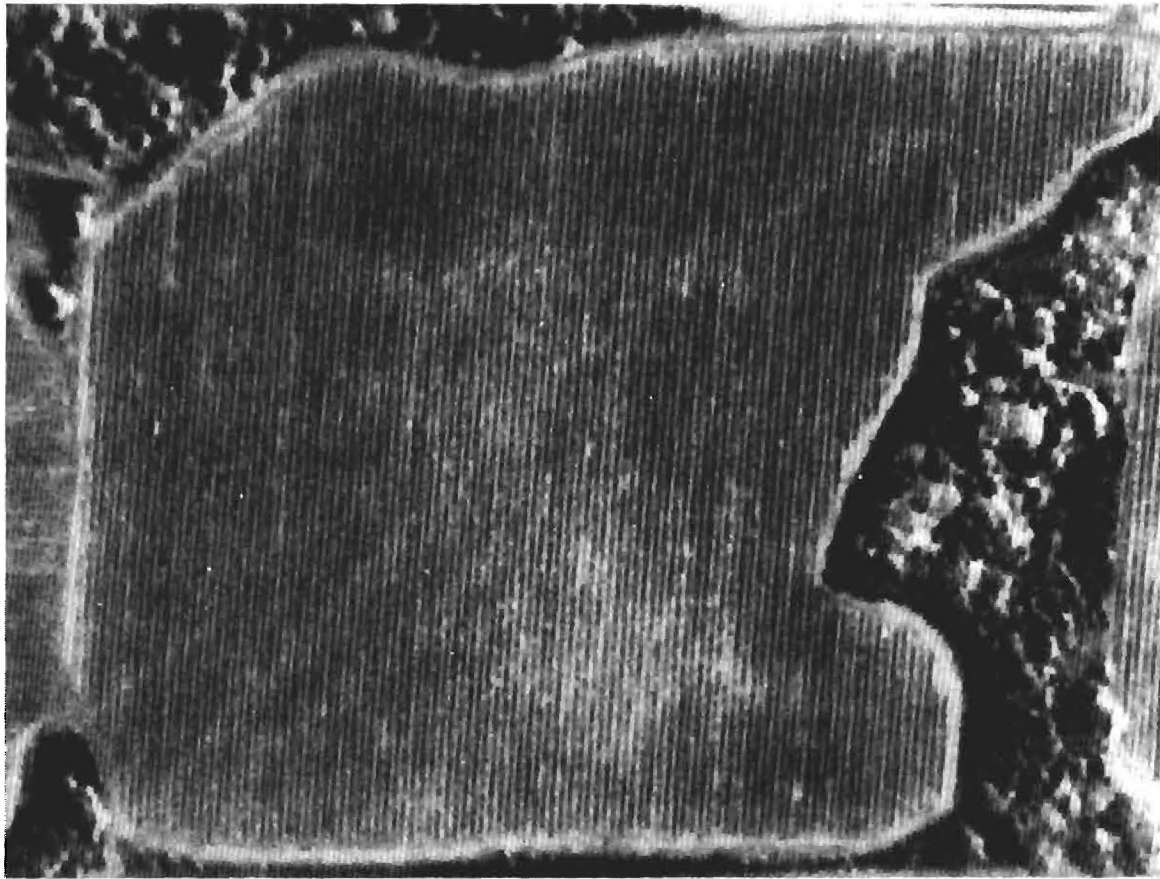


Figure 32. Enlarged Aerial Photograph of Row Crops and the Resulting Fourier Transform Showing Strong First Order Maxima.

spacing of this structure result in strong first order maxima which are easily recorded on the diffraction pattern sampling system.

Fourier transform diffraction patterns of other objects taken from the 70 mm film were recorded on the automatic diffraction pattern analyzer, but these objects did not yield signatures which could be readily analyzed with the present computer analysis programs. It is very likely that the resolution and contrast of the forestry images on the 70 mm film available for this study were not high enough to provide useable diffraction pattern signatures for the present system specifications.

VI. CONCLUSIONS AND RECOMMENDATIONS

The goal of this program was to develop an automatic Fourier transform diffraction pattern sampling system, and to use this system to investigate techniques for forestry classification from six band multispectral aerial photography. The complexity of the system development resulted in the major effort being expended on development and testing of the system hardware. Software efforts were restricted to the generation of computer programs for sampling and recording accurate diffraction pattern representations under widely varying light background conditions.

The system parameters including sensitivity, dynamic range, spatial frequency resolution and adjacent ring cross coupling were measured, and system performance criteria based on these parameters were suggested. Performance tests with grating type objects showed that the system is capable of recognizing and accurately determining object geometries from the measured diffraction patterns. Further, these tests clearly showed the potential advantages of this system over photographic-densitometer techniques for optical pattern recognition.

In addition to establishing diffraction pattern sampling criteria, the system tests revealed several areas where improved electronic performance and changes in optical parameters would be advantageous. For example, maximum utilization of the highest resolution possible with cameras and films intended for aerial photography would require that the focal length of the Fourier transform lens be reduced from 59.89 cm to about 16 cm for a source wavelength of 488 nm. This change would result in the fiber optic detector encompassing at least two diffraction maxima for any barely resolved object. Improvement in the system sensitivity to accommodate diffraction pattern signatures of low contrast objects (such as forestry images) is also needed. An increase of about 5 dB in system sensitivity could be obtained by an improved photodiode mounting scheme which would reduce the fiber bundle to photo-diode element spacing. Beyond this relatively simple improvement, consideration should be given to incorporation of higher quality, low noise, operational amplifiers following the

photodiodes. Another interesting possibility would be to combine an additional electronic gain stage, possibly between the high level commutator and the A/D converter, with improved front end gain to vary the 36 dB dynamic range window up and down the absolute sensitivity scale. Finally, the requirements on laser amplitude stability for the present system sampling time interval were found to far exceed the capabilities of off-the-shelf laser devices. However, there appears to be several potential solutions for this problem. As discussed in Section V, an external feedback loop with the sample point in the expanded and spatially filtered beam would greatly improve amplitude stability. The error signal generated at this sampling point could also be injected into the reference voltage ports of the current-to-voltage converters in proper time sequence with the commutation operation. Still another possibility would be to record the error signal and perform the intensity adjustment in the digital processor. On the other hand, the requirements on amplitude stability would be greatly reduced if the 169 rings were sampled in parallel, and interrogated sequentially by means of sample and hold circuits following each of the operational amplifiers. These techniques and possibly others should be carefully evaluated to determine the optimum solution which would be both cost effective and satisfy the technical requirements.

The above system considerations apply to improvements in the accuracy of sampling and recording diffraction pattern signatures. It is imperative, however, that equal consideration be given to the development of effective algorithms for pattern recognitions processing. The system in its present state is suitable for preliminary development of processing operations for land use classification. A beginning step would be the investigation of art work photographic transparencies to determine the effects of contrast ratio and object shape on diffraction pattern signatures. At the same time, algorithms should be developed for recognitions of simple objects, and an investigation of the possible advantages of combining or weighting the outputs of the concentric rings electronically should be included.

Since spectral information is available from the aerial photographs at the undiffracted light location of the Fourier transform diffraction

pattern, careful consideration should be given to multiband processing techniques. A combination of spatial signature features plus spectral intensity would possibly provide a means for discriminating between different objects having similar shapes, and would lend itself to integration with well established digital processing techniques which are now applied to the analysis of multispectral earth resources data.

In summary, the power of optical processing in pattern recognition has long been recognized, but at the beginning of this program, methods had not been available for automatic sampling and processing of Fourier transform diffraction pattern signatures. A hybrid optical-digital system has been developed on this program as a first step toward the development of a real time optical processing system. Time and funding resources available to this program did not permit extensive development of algorithms for digital processing of the six band multispectral aerial photographs made available by MSFC for analysis. Tests were performed and results were documented to reveal the accuracy for which Fourier transform diffraction pattern signatures could be sampled and recorded by the system developed on this program. These tests led to the identification of changes which should be made in the system hardware for improved diffraction pattern analysis. It is recommended, however, that the system in its present configuration be employed in a preliminary investigation of processing techniques for land use classification. Ideally system improvements and a study of processing techniques should be pursued concurrently. The initial steps for such a program effort have been outlined, and it is recommended that this program effort be continued toward development of an optical processing system for real time land use classification from a conventional aircraft or satellite platform.

VII. ACKNOWLEDGEMENTS

The authors would like to acknowledge the technical contributions of Messrs. A. McSweeney and J. B. McManus to the optical systems measurements and analysis, the efforts of C. S. Wilson, Jr. in the design and fabrication of the optical-electronic interface, and R. D. Wetherington for assistance with the computer programming.

VIII. REFERENCES

1. Lipson, S. G., and Nisenson, P., "Imaging Characteristics of the ITEK PROM," *Applied Optics*, 13, No. 9, pp. 2052-2060, Sept. 1974.
2. Shanks, I. A., "Liquid Crystal Materials and Device Developments," ELECTRONIC ENGINEERING, pp. 30-37, Aug. 1974.
3. Donjon, J., et al., "A Pockels-Effect Light Valve: Phototitus Applications to Optical Image Processing," *IEEE Trans. Elec. Dev.*, ED-20, No. 11, pp. 1037-1042, Nov. 1973.
4. Smith, W. D., and Land, C. E., "Scattering-Mode Ferroelectric-Photoconductor Image Storage and Display Devices," *Appl. Phys. Lett.*, 20, No. 4, pp. 169-171, Feb. 1972.
5. Lenduris, G. G., and Stanley, G. L., "Diffraction-Pattern Sampling for Automatic Pattern Recognition," *Proc. IEEE*, 58, No. 2, pp. 198-216, Feb. 1970.
6. Nyberg, S., et al., "Optical Processing for Pattern Properties," *Photogrammetric Engineering*, 37, pp. 547-554, 1971.
7. Gramenopoulos, N., "Finding the Earth in ERTS," Optical Spectra, pp. 26-28, Aug. 1974.
8. Feinleib, J., "Optical Processing in Real Time," Laser Focus, pp. 42-44, Sept. 1973.
9. Vander Lugt, A., "Coherent Optical Processing," *Proc. IEEE*, 62, No. 10, pp. 1300-1319, Oct. 1974.
10. Dobrin, M. B., "Optical Processing in the Earth Sciences", IEEE SPECTRUM, pp. 59-66, Sept. 1968.
11. McSweeney, A., "Design and Fabrication of an Engineering Model Fiber-Optics Detector," Final Report on Contract NAS8-28215, Georgia Institute of Technology, Dec. 1972.